TELESCOPE MAKING 5

ISSN 0190-5570

The magazine *for, by,* and *about* telescope makers!

Fall 1979

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all the details

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TELESCOPE MAKING

The magazine *for, by* and *about* telescope makers!

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Editorial

This issue of TELESCOPE MAKING marks our entry into a second year of regularly publishing more pages and words of hobby-level information about telescopes than any other outfit in the world. TM has come of age in another sense also, because I've got far more material on hand for this issue than I can possibly publish.

That's both encouraging and discouraging. I'm pleased because it means I have to worry less about the next issue — I've got enough here to publish a nice fat 48-page issue of TM#6 right now. But I'm discouraged because it means there's now a waiting line for anyone who sends me an article. It also means running a risk of getting stuffy and too formal. Getting into print quickly keeps the old idea-glands flowing.

I've tried to find strategies for getting around these problems, seeking ways to more-or-less guarantee prompt publication, usually by the next issue. Here's what I've decided:

- You'll notice this issue is something of an "observatory" issue. From now on, though, I'm placing an informal moratorium on articles about observatories — I've already sent back a few in fact. Instead, I'll publish short notes on observatories concentrating only on new ideas or unique features, perhaps devoting a page to each.
- Next, we'll drop announcing an issue topic ahead of time and I'll organize articles into topical issues based on what I've got on hand. (Small gripe: You readers have a terrible habit of sending me articles for pre-announced topics after I've put the issue to bed.) This issue, #5, is a special-topic issue on observatories, and I'll hold over the articles originally scheduled on mirror grinding and polishing until TM#6, which will also carry the articles on beginner's telescopes.
- Next, I'm expanding the Letters department to serve as a better information exchange market. Lots of goodies can be conveyed via letters, and you meet more people as a result. I may run short submissions as letters rather than articles. TMs are a mixed lot, some gregarious and others not, but Letters can bring everybody into communication with others all over the world.

I think these changes will help Bob Cox, Kathy King and myself keep TM lively and full of interesting new stuff. Don't slack off sending in articles — there'll be space for them one way or another!

A number of people have asked about deadlines. TM goes out to the printer on March 21, June 21, September 21, and December 21, which makes the dates easy to remember. I need articles at least one month before those dates, and material submitted to Bob Cox needs about six weeks. After the issue is printed, which usually takes a week, it takes three more weeks to reach you in the mail. This issue is going out about two weeks late because the time I spent in California covering the Voyager 2 Jupiter flyby threw my schedule off kilter. The next deadline, for submissions to TM#6, is sometime around November 21.

Sincerely,

Richard Berry

Richard Berry

Letters

Dobsonian Blanks

Dear Sir / After reading Bob Kestner's article on the Dobsonian reflector in TM4, I decided that a Dobsonian was the type of telescope that best fit my needs and budget. In part 1 of his article, Mr. Kestner specified using a thin plate glass or pyrex mirror for the objective. Are there any companies you might suggest that sell plate glass mirror blanks or finished plate glass mirrors for astronomical use with thicknesses of around 1-inch? Would the grinding and polishing procedures be the same for plate and pyrex sheet glass as they are for standard-thickness pyrex blanks? Any information you could give me answering these questions would be greatly appreciated.

Peter M. Rubinelli
10419 S. Talman Ave.
Chicago, IL 60655

Dear Mr. Rubinelli / The classical source of plate glass in the San Francisco area has been porthole glass from ships. Try a major supplier of window glass in your area for plate glass.

Pyrex is available from the United Lens Company of Southbridge, MA 01550, in thicknesses from 3/8" to 1-5/8". They can supply it in "rough round" polygons and for an extra charge will diamond generate a smooth round edge, smooth back, and radius on the front.

Write for their information and price sheets.

Grinding and polishing are apparently done the same as with usual thickness blanks, but more care is taken that the disk rests on a firm yet flexible backing such as a layer of carpet or soggy newspapers. Rather than test with the Foucault test, some mirrors are checked in the completed telescopes (remember, its easy to remove and install the mirror through the tailgate), worked until they're giving good images, then aluminized.

-- R.L.B.

Clarke Objective

Dear Sirs / May I congratulate you on your excellent little magazine TELESCOPE MAKING — keep up the good work.

Letters

I noticed in your last issue a plaintive cry for a source of synchronous motors. Over here in the U.K. they are quite easy to obtain although deliveries are sometimes prolonged for special gear ratios. The prices range from about $12 upwards.

Incidently I have an 8" Alvin Clarke O-G in a Brass Cell (unused! — it was made for the Chairman of Ross Optical and kept in their museum!!). Have you any idea what it's worth in your country?

Looking forward to your next issue.

Dudley K. M. Fuller
"Fullerscopes"
Telescope House
63 Farringdon Rd.
London EC1

Well readers — any offers on this fine objective?

Herback and Rademan for Motors

Dear Mr. Berry / I am writing in response to your question for a source of low-r.p.m. synchronous motors. Enclosed are copies of pages from the current Herback and Rademan catalog listing hundreds of motors of the kind needed in telescopes — and at reasonable prices. Your readers can purchase them directly by mail; minimum order is $12.50, no CODs.

This company carries many items which might be of interest to TM readers — write to the address below for a free monthly catalog:

Herbach and Rademan, Inc.
401 East Erie Avenue
Philadelphia, PA 19134
Phone: 215-426-1700

I'm sure Mr. Sandy wouldn't have had as many problems dealing with this company as he had with North American Phillips.

Marcus A. Naito
P.O. Box 177
Delano, CA 93216

Dear Mr. Naito / Thanks. This catalog has everything! In 100-inch-ounce torque reversible heavy duty synchronous motors ($22.45 each), you can get the following r.p.m. s: 1/3, ½, 1, 1½, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 30, 40, 60, and so on. Also many motors, meters, magnetic clutches, and much, much more.

Rays to Trace

Dear Sir / Several articles in TM dealt with catadioptric telescopes in which the optical train was designed or evaluated using computerized ray-tracing programs.

How about an issue dedicated to these techniques? I believe it's safe to assume most readers have a programmable calculator and a working knowledge of calculus.

Such an issue should emphasize coma, chromatic and spherical aberration, as well as eyepiece design. Also several articles on the quantitative evaluation of functional optical systems should be included.

With the appearance of hybrid optical trains over the last 10 years, I feel that it is essential to have a working knowlege of ray-tracing so that the ATM can evaluate his design choices.

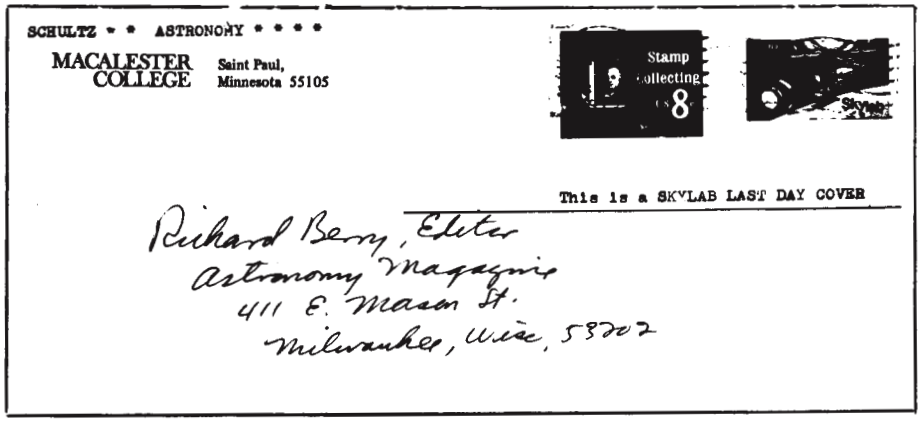
Thank you.

Phillip Trosko
P.O. Box 1231
Troy, MI 48099

Dear Mr. Troy / There's an old saw: "a little knowlege is a dangerous thing," and what that means for TM is that any issue we devote to ray-tracing must necessarily provide a lot of knowlege — a huge amount — to get past the danger point. I'm sure we'll do it some time. For the time being, we strongly recommend that you use **Lens Design Fundamentals** *by Rudolf Kingslake (published by Academic Press, New York, 1978, ISBN 0-12-408650-1; shelved under QC 385.2 in libraries using the Library of Congress system or 681.42 in the Dewey Decimal System) as your source of information. This book covers most of the topics in ray tracing you suggest, plus more. Another superb reference is* **Modern Optical Engineering** *by Warren J. Smith (McGraw-Hill, New York, 1966), found in the TS 513 section of the library.*

-- R. E. C. & R. L. B

48 ➤



"This is a Skylab Last Day Cover"

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TM5

Stel

Stellafane usually makes me think of pine trees and cool, sunny Vermont weather. Up there on Breezy Hill, I expect the wind to bring that wonderful whiff of cool resinous-smelling air out of the woods, and stepping into the woods, to find cool, damp, mossy spots in the mixed stands of pine and birch and luxuriant clumps of ferns in occasional open places. The rocks sticking out of the soil tell me I'm back on the east coast.

Stellafane also makes me think of telescopes; the thrill of my first year there, 1964; and the subsequent pilgrimages in '66, '67, and '78. Stellafane is a place to find ideas and a place where good ideas, new ideas,

lafane

clever ideas are appreciated. I've always gone there to learn something, to pick up a hint here, a variation there, and a new slant on drives, circles, glass pushing. I've always left richer than I came.

Stellafane is steeped in history, or at least a sense of the past. The little pink clubhouse is filled with memorabilia: the original plaster casts for the figuring articles in *Amateur Telescope Making*, Porter's sketches, the old transparencies of 100" Hooker pictures, and the pungent smell of Walter Scott Houston's pipe.

There's also the Porter Turret telescope, that massive lump of concrete perched on Vermont bedrock — an odd-looking contraption even after you figure out how it works — bearing the numerals "1930" on the north side. And that, you find youself thinking, was 49 years ago.

This year, because the date of the August new moon conflicted with Labor Day, Stellafane was held in late July. Perhaps because of some subtle interplay between vacation dates, the weather, and holiday schedules, the attendance of people was up (the parking and camping fields were jammed), but the number of telescopes seemed down (there were fewer up on the hill than I ever remember before). The weather was hot, rather muggy, and the afternoon sunlight each day was attenuated by clouds.

I took it easy this year, stayed at Hartness House (hot running water, a shower, spacious rooms, superb food, and comfortable beds) rather than camping, wandered around talking to people rather than playing reporter and attempting some kind of "complete coverage," and I didn't attend the paper sessions but instead got away into the woods.

There were a number of extremely

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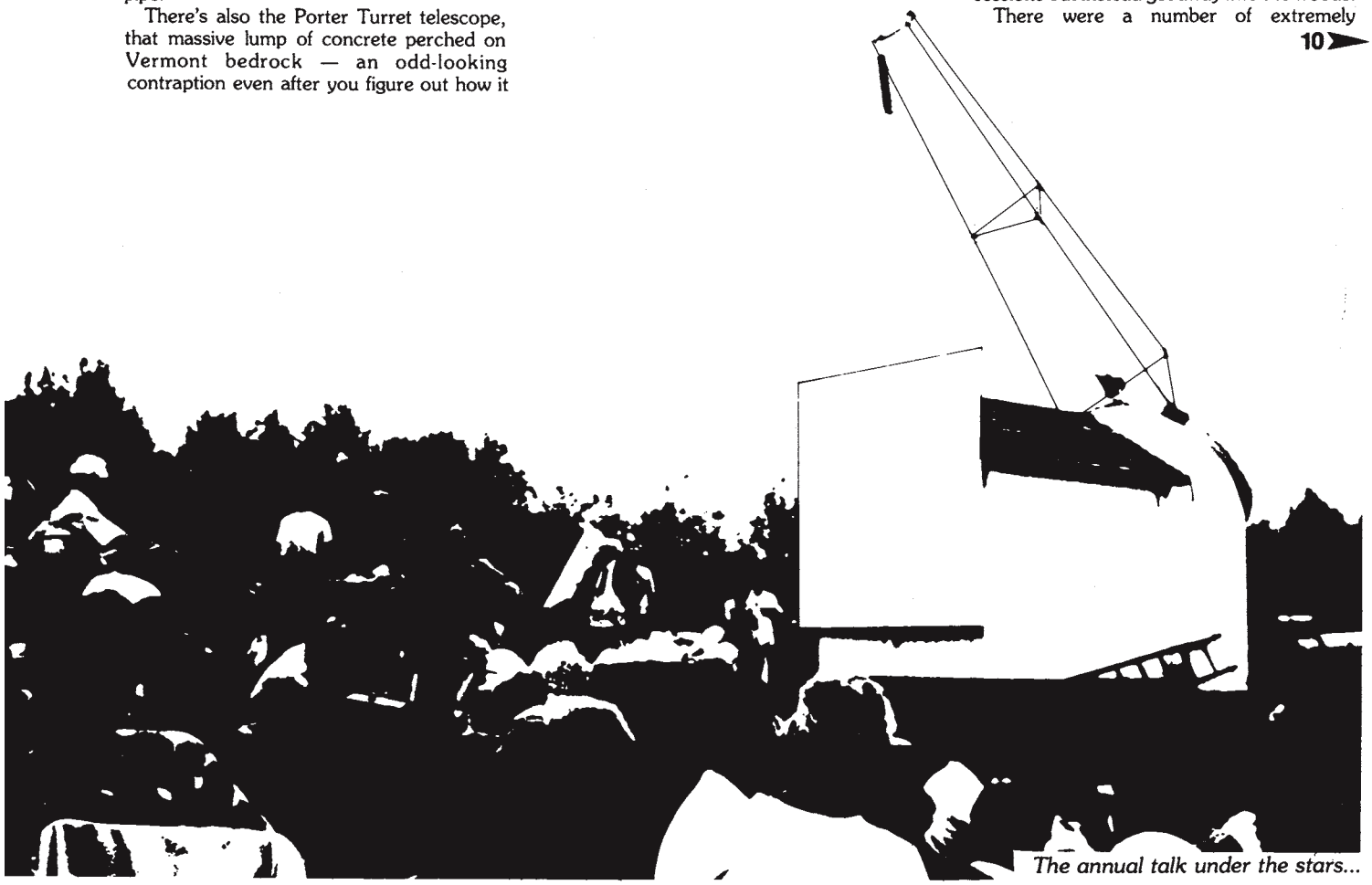
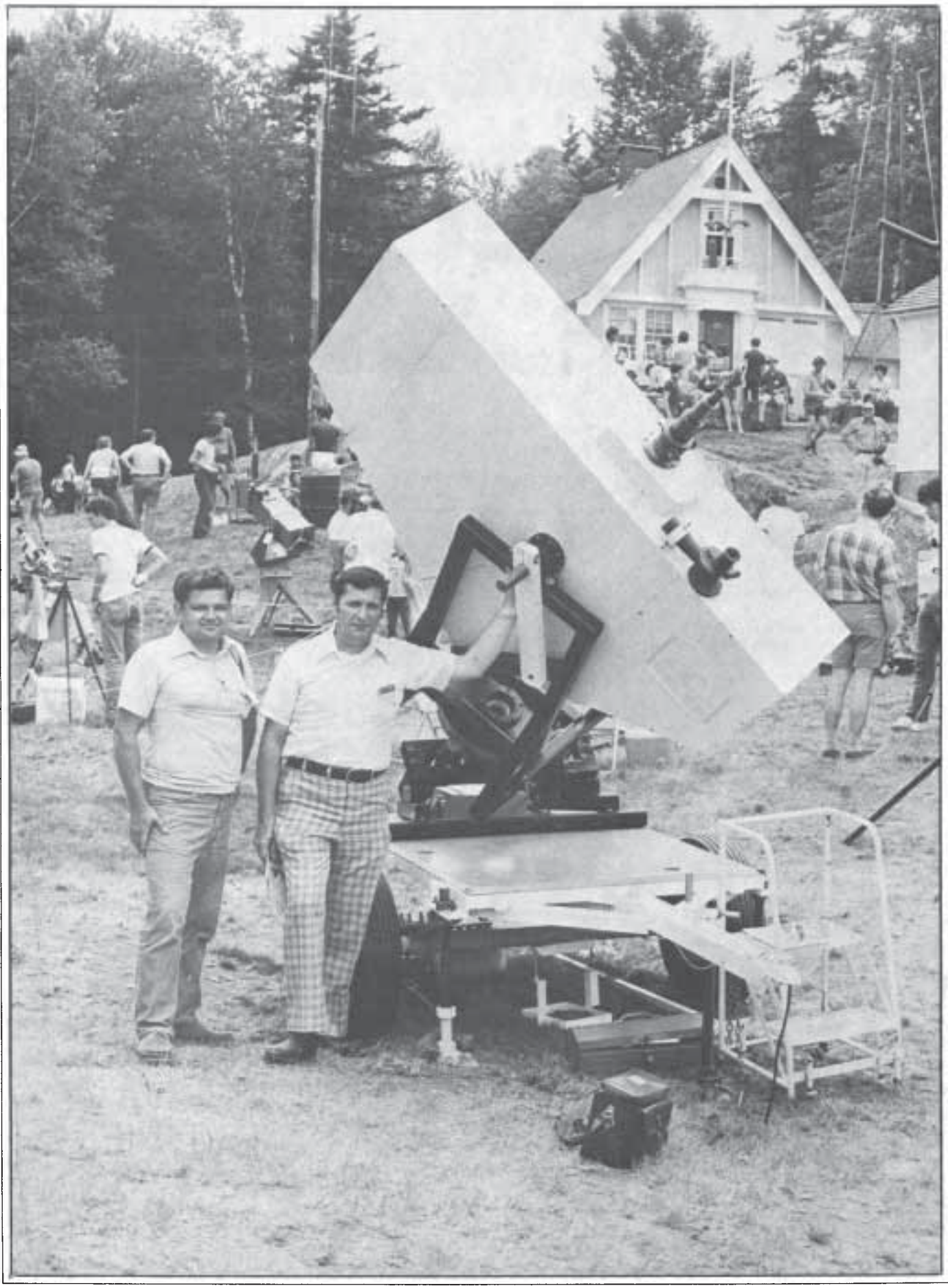
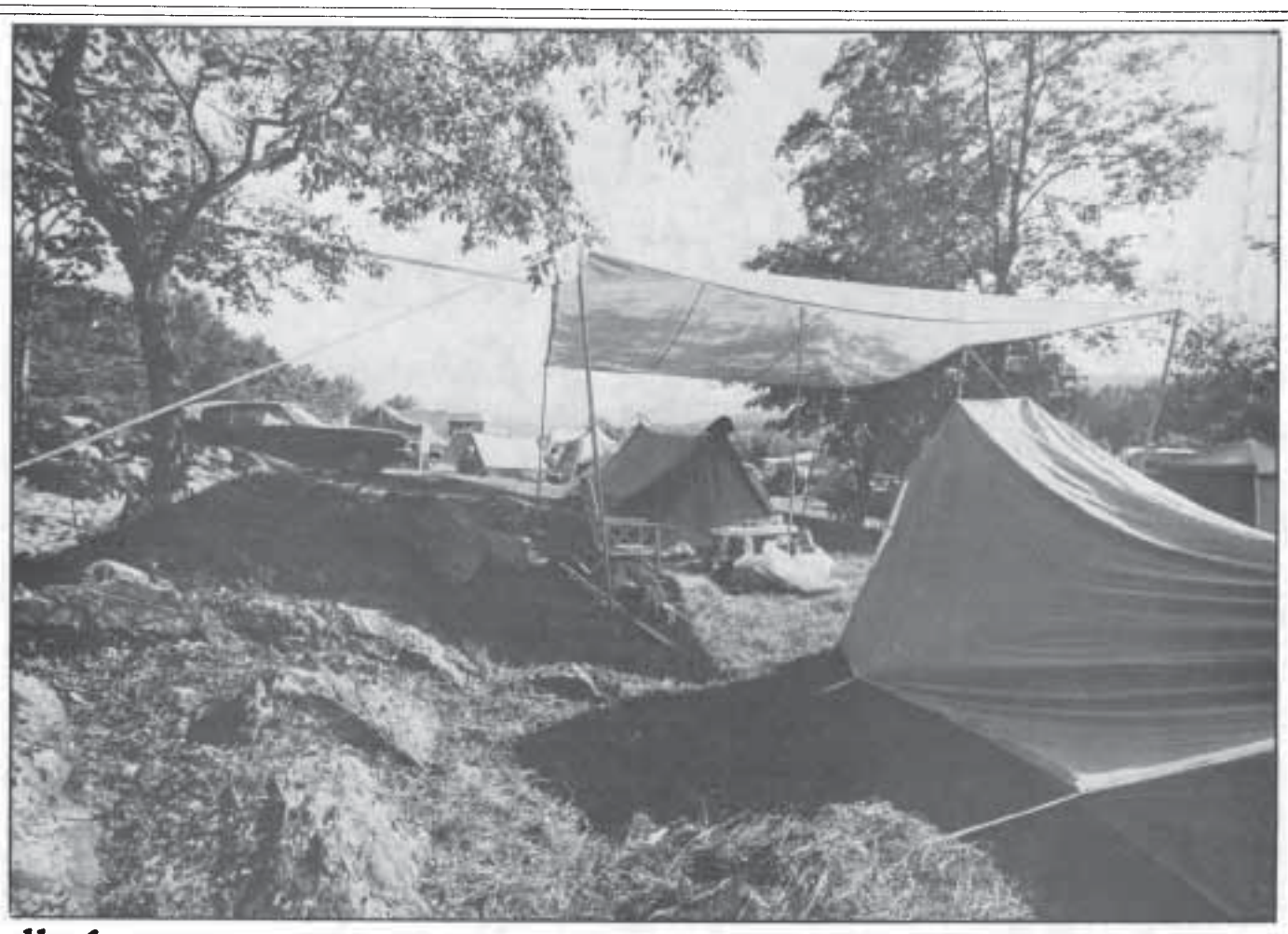


The annual talk under the stars...



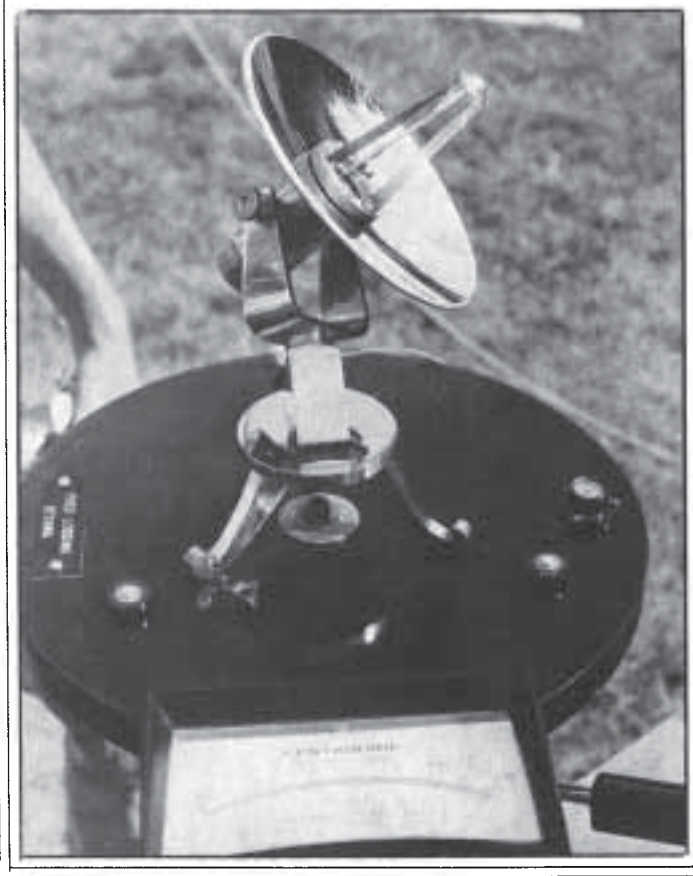


Stellafane

Perry Remaklus (left) and Jean Paul Prideaux stand in front of their12.5" tri-schiefspiegler. Together they made two sets of optics - this instrument is Prideaux's.

Camping is an old tradition at Stellafane. However, laser- aligned tents has never been tried before!

Many optical and mechanical gadgets exchanged hands at the swap meet table this year.



Stellafane

◀◀◀ *Fred Lossing of Ottawa built a solar energy demonstrator.*

◀◀ *"Hello, I'm Mintaka, the talking telescope," said this 3" refractor built by David Levy, Constantine Papacosmas, and Michael Stoffregen of Montreal.*

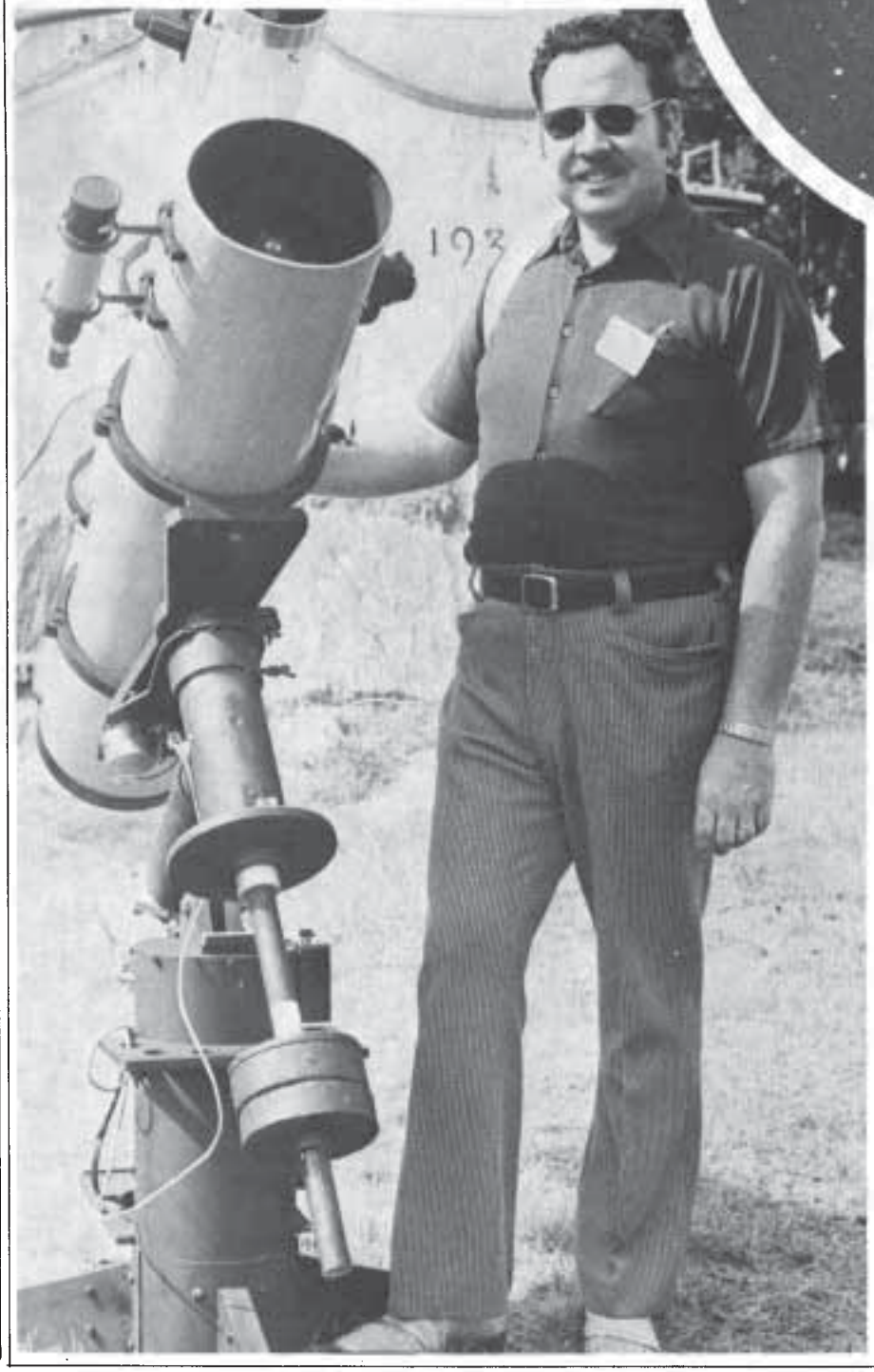
◀ *Andreas Gada of Toronto built a mini-telescope with a 42 mm f/2.5 mirror.*

Multiple Mirror Telescope taking shape. See text for details. ◀

interesting telescopes present, however, and these I investigated.

Most interesting, at least in the sense that it was unusually big for its type, was the 12" f/14.7 tri-schiefspiegler built by Jean Paul Prideaux and Perry Remaklus of Richmond, Virginia. It was a huge trailer-mounted, white-painted, seven-sided plywood box, pentagonal in outline, dominating the view of the hill. The primary is a 12.5" mirror, the secondary and tertiary are 8-inchers.

Together these two ambitious ATMs had ground two complete sets of optics, one for each of them. The telescope, mount, and trailer unit at Stellafane this year was Jean Paul's; perhaps in another year we'll see the Remaklus version of the same set of optics. Specifications for the optics are: primary 12.5" diameter, R. of C. 254", 56% paraboloidal; secondary 8.0", R. of C. -370.8", spherical; tertiary 8.0", R. of C. 2046.0", spherical (details on this optical system are found in *Sky and Telescope*, January and February 1975 issues).



"Alignment is a problem," according to the builders, who spent much of one evening trying to coax out the astigmatism.

Equally impressive in its own way was Andy Tomer's meticulously crafted 12" f/15 trailer-mounted Cassegrain. A great deal of surplus hardware, greatly re-machined, combined with beautifully anodized new work, gives the instrument a thoroughly professional look and feel. Tomer has employed several superbly executed design innovations: the use of belt drives in both axes (smooth operating and superior to worm drives), electrical control azimuth and elevation controls (permitting fast polar alignment), use of a tachometer-controlled DC motor (formerly a tape transport motor), and a welded box trailer with fold-down legs that made his the most stable transportable telescope I've ever seen. According to Tomer, "Happiness is a working servo-motor."

Tomer's version of the band drive employs eight strands of braided steel cable rather than Boston rollerless chain ("bicycle chain") or a flat strap ("tape measure refill") previously described in telescope making literature. The stuff seems to work well under great tension, yet it's very flexible and readily available. One disadvantage is that the two tie-down points at the ends of the wire mean the drive cannot run continuously forward.

George Chaplenko had an interesting lightweight wooden fork and mounting, very portable, notable for its use of hollow structural members. He used 1 x 3s for side pieces and ⅛" mahogany veneer for cover plates. The tripod that supports the fork-

Walter Hamler, of Waldorf, Maryland, uses his 8" f/5 reflector to take pictures like the "Trio in Leo" at upper left. He uses a 4" f/13 guide scope, Schmidt drive in RA and tangent arm for Dec. corrections. Of a well-composed picture of the Pelican Nebula, Walter says, "I got it all because I could see the Pelican through the viewfinder."

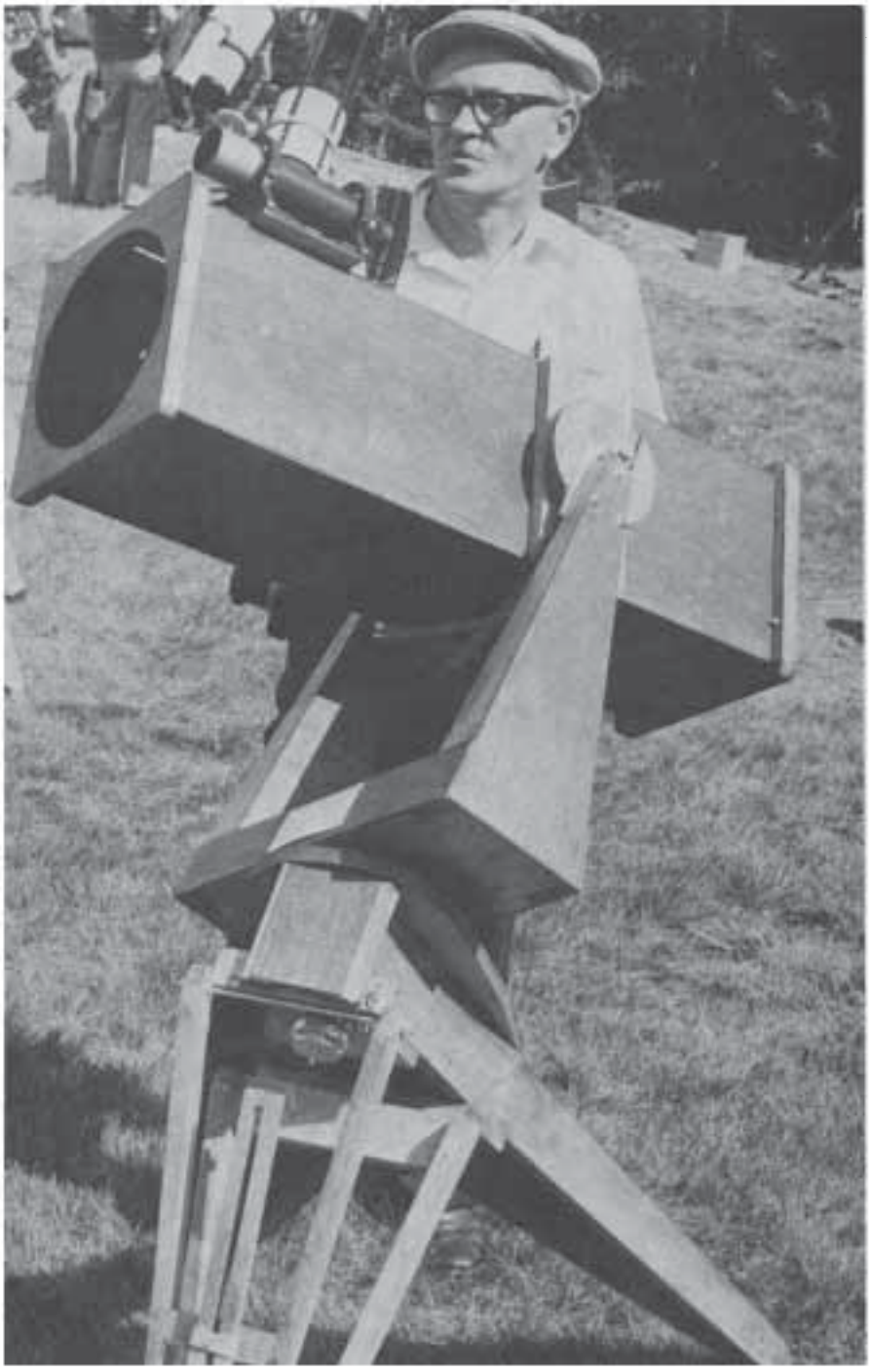
mounted telescope, built with the same methods, folds down for easy carrying in an automobile.

"You have to imagine a lot because it's not finished yet," said Harald Robinson and Ken Laune of their [(1" x 8") + (4" x 6")] multiple mirror telescope. Equivalent when combined to a 14.4" f/7.5 telescope, the 19 reflecting surfaces that will make up the optics of the "mmt" will consist of four 6" Cassegrains of 108" focal length and a central 8" Cassegrain. Light from each of the 6" instruments will bounce off two flats — one to bring it over next to the beam from the 8" and another to reflect it parallel. All five converging cones of light will reflect from one more flat mirror to bring the beam out the side at the rear of the instrument.

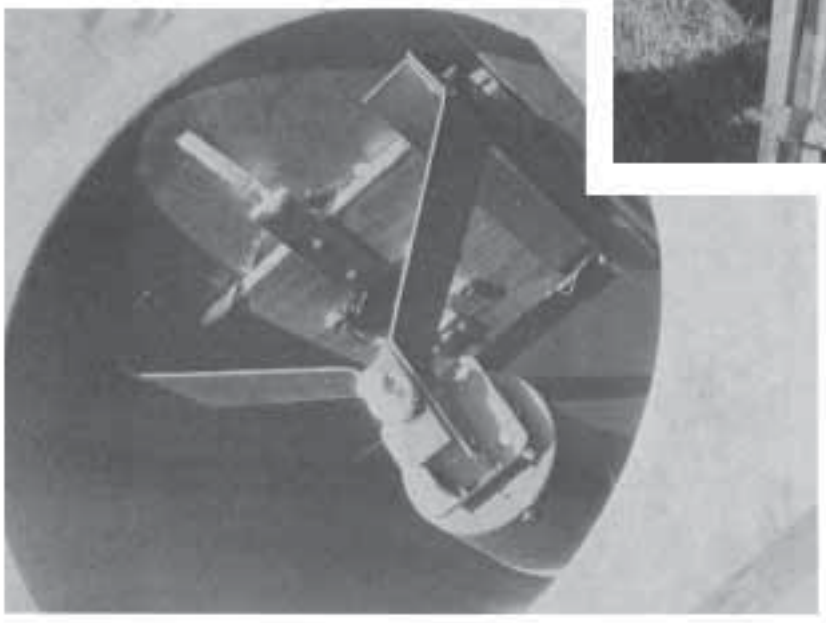
Such a design obviously places stringent requirements on optics (maintaining precise focal lengths) and mechanical supports (retaining optical alignment). The instrument is built into an "old satellite frame we found in a junkyard in Lexington (MA) about 12 years ago"; the handsome-looking fork mount consists of "plywood fork + body filler + gray Rustoleum."

I'll be looking forward to seeing it perform, hopefully next year!

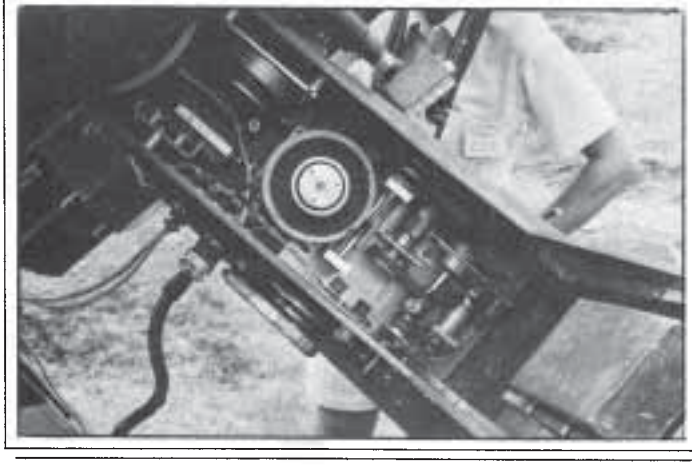
Finally there was Mintaka, the talking telescope. At least that's what she called herself. Mintaka is a 4" Unitron refractor mated with a speaker cabinet, tape recorder, two flat mirrors, and an alt-azimuth mounting (which unfortunately turned too easily). Mintaka, named after one of the belt stars in Orion, was conceived by David Levy, Constantine Papacosmas, and Michael Stoffregen, of Montreal. ■

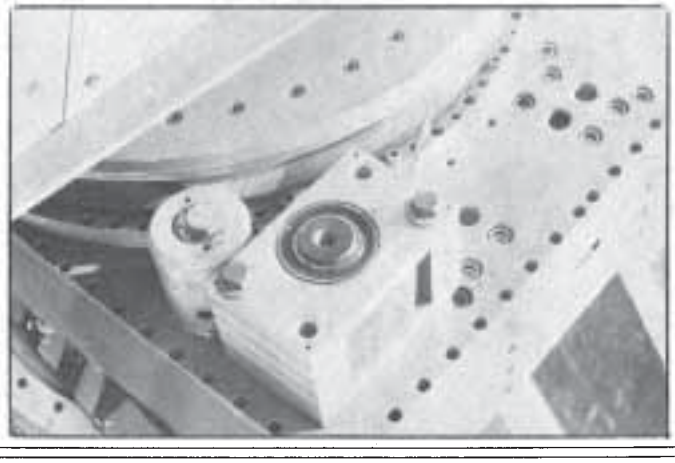


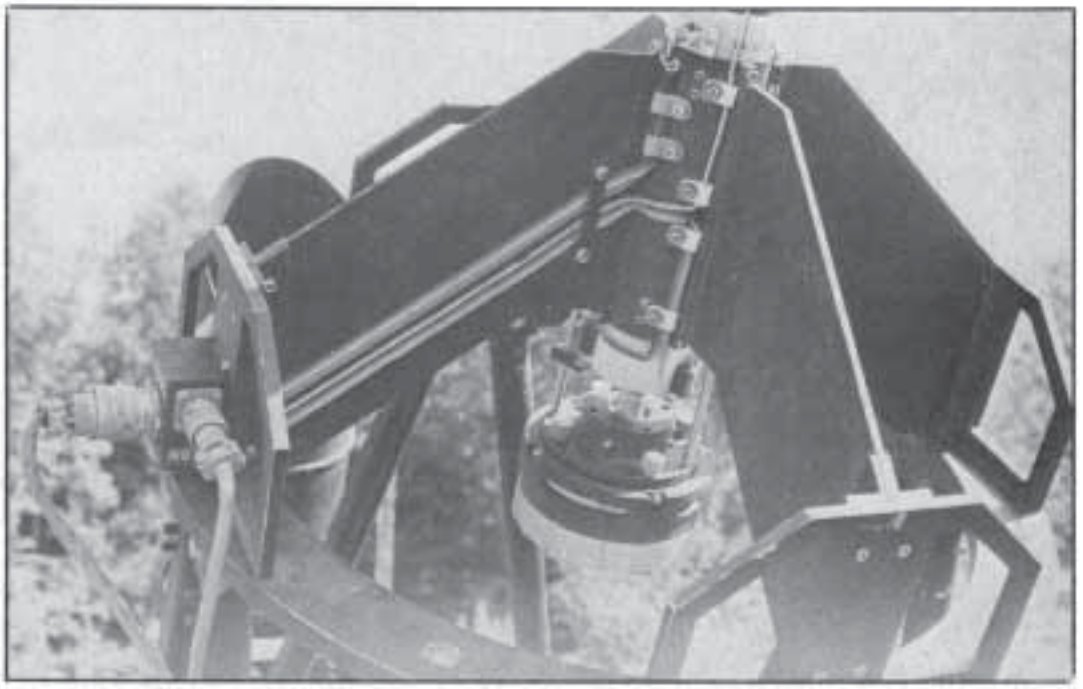
George Chaplenko, of Edison, N.J., showed off his 8" RFT with pride. "It's all hollow structures, 1 by 3 pine and 1/8" mahogany veneer." The tripod folds for easy carrying.

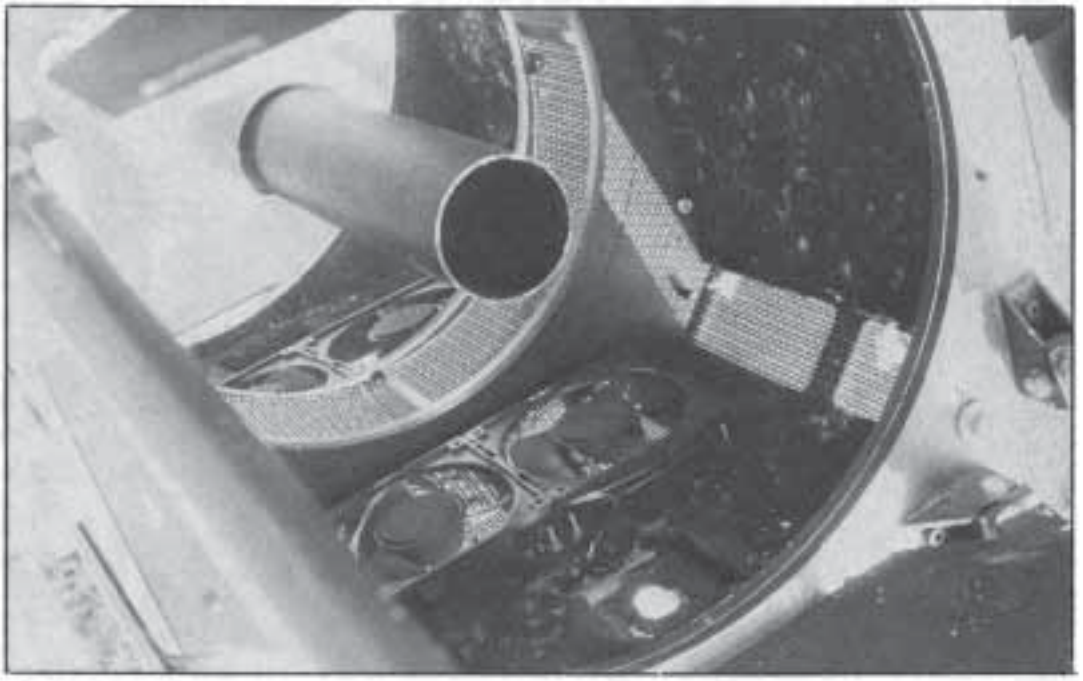


The secondary mirror and focuser move together in Mr. Chaplenko's simple yet functional eyepiece carrier.









Stellafane

This impressive trailer-mounted 12" f/15 Cassegrain reflector was always surrounded by a large crowd. It was built by Andy Tomer, of Watertown, Mass., with a lot of surplus gear.

Feature: Works of the declination drive, motors power roller of steel-band drive.

Feature: electrical focusing and remote readout of focus position.

Feature: drive unit for R.A. steel band drive; small roller is driven by tape transport motor controlled through a feedback system by a tachometer.

Feature: Sexy perforated chassis material and muffin fans for effective control of air currents.

Feature: Massive trailer supports that fold up when not in use.

The instrument was built over a five-year period.

The Dobsonian Telescope–II

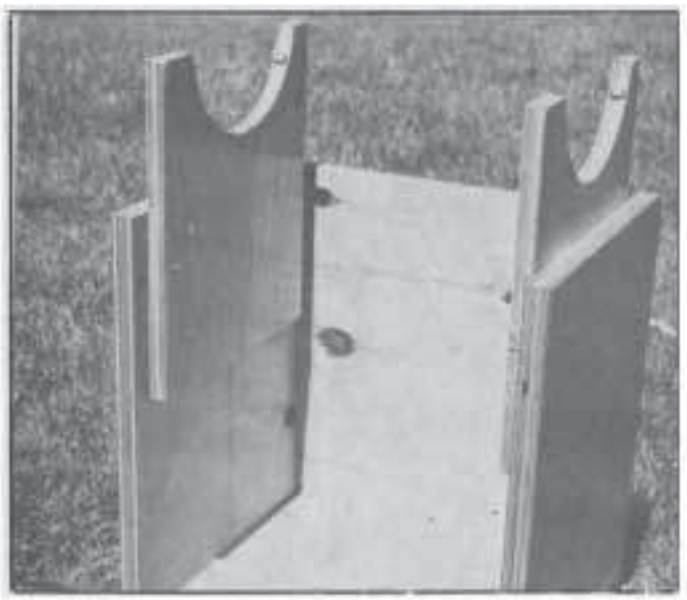


fig. 1 The rocker for a 10″ telescope

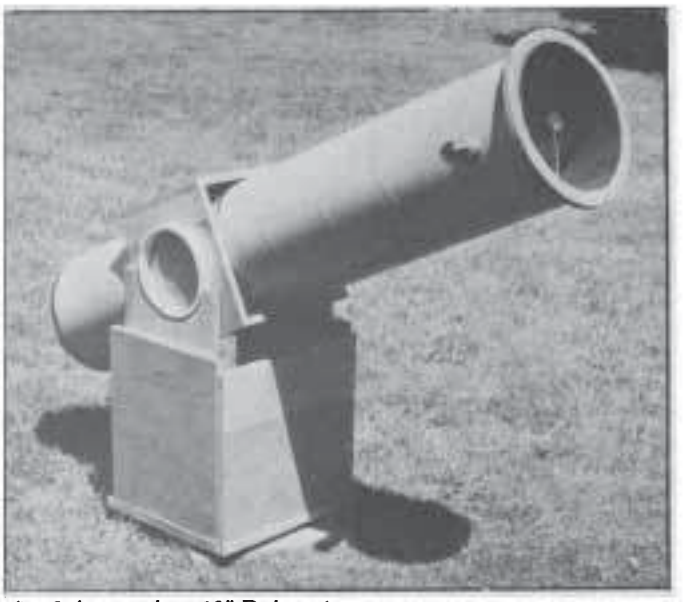


fig. 2 A complete 10″ Dobsonian

Building a telescope is a fulfilling and beautiful experience. The rewards of the work can be enjoyed for numberless hours on countless nights. Furthermore, it is an endeavor open to any interested person — of whatever financial means. The instructions that follow will show you how to build one of the simplest and most effective telescope designs ever invented: the Dobsonian telescope.

My knowledge of the Dobsonian type of telescope, which I want to pass on to you via this article, was gained over the years through my own experience in building many of them. But I owe that experience to the efforts of John Dobson and, I suppose, in part to my own stubborn persistence in building so many telescopes.

Dobsonian Terminology

Dobsonian-type telescopes come both large and small, but all have certain features. We'll begin by getting familiar with the names of the parts that make a Dobsonian, starting at the very bottom. Look at fig. 1 & 2. The whole telescope sits on 3 blocks of wood called the feet (shown in fig. 8). The feet are attached to the underside of the ground board. Attached to the top side of the ground board are 3 teflon pads, and riding on the pads is a sheet of formica. The whole arrangement is called the bottom bearing.

The bottom board may simply sit on the formica sheet, or it may be glued to it. Passing through the bottom board, and holding the whole arrangement together at the middle, is the center bolt. The formica sheet turning on teflon pads is an extremely smooth bearing, yet it's almost unbelievably simple.

The bottom board is the bottom of the box, called the rocker, that supports the telescope. Two side boards are attached to the bottom board facing each other. They carry the weight of the telescope. Another piece called the front board, attached to both side boards and the bottom board, keeps the side boards rigidly upright. Two cradle boards, with half-circles or V-notches cut out of them, are attached to the inside of the side boards (although in some variations, they are cut out of the tops of the side boards), and these are what the telescope actually swings between.

Riding on the cradle boards are two round disks (one on each side attached to the box-shaped end of the telescope's tube) called the side bearings. These bearing are held in place by the weight of the telescope.

The telescope's tube, usually round cardboard concrete-form tube, sticks out one end of the box. On big Dobsonians, the other end of the box has a door, the tailgate, which holds the mirror. The mirror rests on 3 tailgate bolts that support it and allow for collimation. If the telescope has a large thin mirror, the mirror hangs in a sling and "ears" protrude from each side, preventing the mirror from falling down the tube (fig. 12).

Getting Started

The dimensions of the Dobsonian telescope's parts, especially the dimensions of the rocker, rely on the diameter and length of the tube. Naturally. And the size of the tube, of course, relies on the diameter of the main mirror and its focal length, so the very first step is to determine what size and focal length mirror you want. That is up to you, but remember that inch-for-inch a Dobsonian is a more portable telescope than a conventional Newtonian of the same aperture, so be

An 18″ Dobsonian overlooking Half Dome in Yosemite National Park

courageous and think big! But also, for practicality, think short. With telescopes in the 16″ size range, f/5 is a practical focal ratio.

Now to the dimensions. Choose, for the inside diameter of the tube, a dimension enough larger than the diameter of the mirror that air currents in the tube don't pose a problem. However, the i.d. of the tube shouldn't be too large or the size of the diagonal and the entire telescope will increase unduly.

It's been my experience (for tubes made of material having good insulating quality) that 1″ clearance around mirrors up to 18″ diameter suffices. Half-inch clearance is adequate for little mirrors in the 3″ to 5″ range. The length of the tube is usually just about the same as the focal length of the mirror.

The material you use for the tube is a matter of personal preference; my only recommendation is that it be a thermally insulating material. Tubes made from metal have a high thermal conductivity; this, I supect, is why reflectors suffered the reputation of poor performance in the first part of this century. Most often used for Dobsonians are tubes made for construction called concrete form tubes. These tubes, made of heavy rolled paper, are in my opinion better suited for telescope tubes than for making the concrete pillars for which they are intended! They come in diameters stepped in 2″ increments — but that depends on the individual supplier.

After determining the dimensions of the tube and buying the material (so you don't get stuck afterward if you can't find the tube size you wanted), you're ready to move on to determining the dimensions of the tube box and rocker. You must make sure of three things:

- First, there must be enough clearance between the inside of the cradle boards and the outside of the tube's box to allow rub-free movement. (It is also a good idea to allow enough space for a small piece of teflon to be nailed to the inside of each cradle board.)
- Second, the bottom end of the tube mustn't hit the bottom board when pointed to the zenith. You can be absolutely sure of this if you build the entire tube assembly first and then determine its balance point.
- Third, the tube mustn't hit the top of the front board until it's pointed horizontal or a few degrees past. It's extremely helpful to draft an accurate scale drawing to make sure your dimensions are correct.

More on Dimensions

It is very important to use wood thick enough to support the scope without flexure. Here are some general suggestions:

- ½″ plywood will suffice for telescopes less than 6″ if the focal length is short. It's also a good idea to double the thickness for the ground board for it must carry the whole telescope.
- For 6″ and 8″ scopes, ¾″ can be used all around with a double thickness ground board.
- For 10″ and light 12″, use ¾″ box, cradle, and front boards, and one inch side boards and bottom board with a 1½″ ground board.
- For 12″ to light 16″, use ¾″ box, cradle, and front board with 1½″ side boards and bottom board and 2″ ground board.
- For heavier 16″ scopes and on into the 20″ class, I recommend ¾″ box and cradle boards.
- Cradle boards for 20″ scopes should be 1″, with 1″ for front boards and 2″ for side and

➤

bottom boards. A 2" ground board will do up to lightweight 20" telescopes, but for heavy 20-inchers and above, the design of the bottom board must be beefed up still more.

In general, you can see that Dobsonian telescopes tend to fall into three main groups: those smaller than 14", those larger than 14" but smaller than 20", and those larger than 20". The major differences lie in several small points of construction due to the increasing size and weight of the telescope.

An Example: a 10" f/6.6

Let's work through an example in the under-14" class, such as the 10" instrument shown in fig. 2. All parts except for 1" side and bottom boards and a 1½" ground board can be made from ¾" plywood. The tube is a concrete form-tube 12" i.d. and 12½" o.d., with ¼" wall thickness.

First the box for the tube must be designed. With a cardboard tube it's a good idea to make the inside of the box about 1/16" less than the o.d. of the tube; this keeps the tube held firm. For stiff tubes that don't warp under pressure, making the box exactly fit the o.d. of the tube is a must. For our 12½" o.d. tube, this gives us a box with an inside width of 12-7/16". Build the box from two side boards having a length equal to the inside dimension of the box and use two boards 1½" longer (because of the overlap) to make the top and bottom.

This gives us four box boards: two 12-7/16" long and two 13-15/16" long. Since it's a good idea to have the box enclose about one diameter of the tube, the final dimensions are:

2 pcs. ¾" x 12¼" x 12-7/16"
and 2 pcs. ¾" x 12¼" x 13-15/16".

The outside dimension of the box is equal to the longest board — 13-15/16". We add the desired clearance to this dimension to get the distance between the cradle boards. We'll add 5/16" for clearance.

Now we know enough to figure out the width of the bottom board. Add: the width of the box + clearance space + thickness of 2 cradle boards + thickness of 2 side boards (13-15/16" + 5/16" + 1½" + 2 = 17¾"). The width of the bottom board must be at least 17¾". It can be larger, but if you want a smooth finish on the side of the rocker, it should be exactly this dimension.

This is also the width of the ground board and front board.

The height of the side boards and the cradle boards depends on the balance point of the telescope tube assembly. This particular 10" balances 22" from the rear. If this distance had turned out to be excessive, I would have added a lead weight (see fig. 4) to the center of the tailgate (lead melts nicely in a can on a kitchen stove). In this case, no weight was necessary.

To that 22", we'll add 2" for safe clearance. This means the top of the cradle boards must be 24" from the bottom board. Considering the 8½" diameter side bearings, the 24" height was divided into 18" of side board and 6" of cradle board, leaving a bit over 2" between the top of the side boards and the bottom of the side bearings. (It would have been possible to lower the cradle boards by this amount if the balance point was too near the end of the tube.)

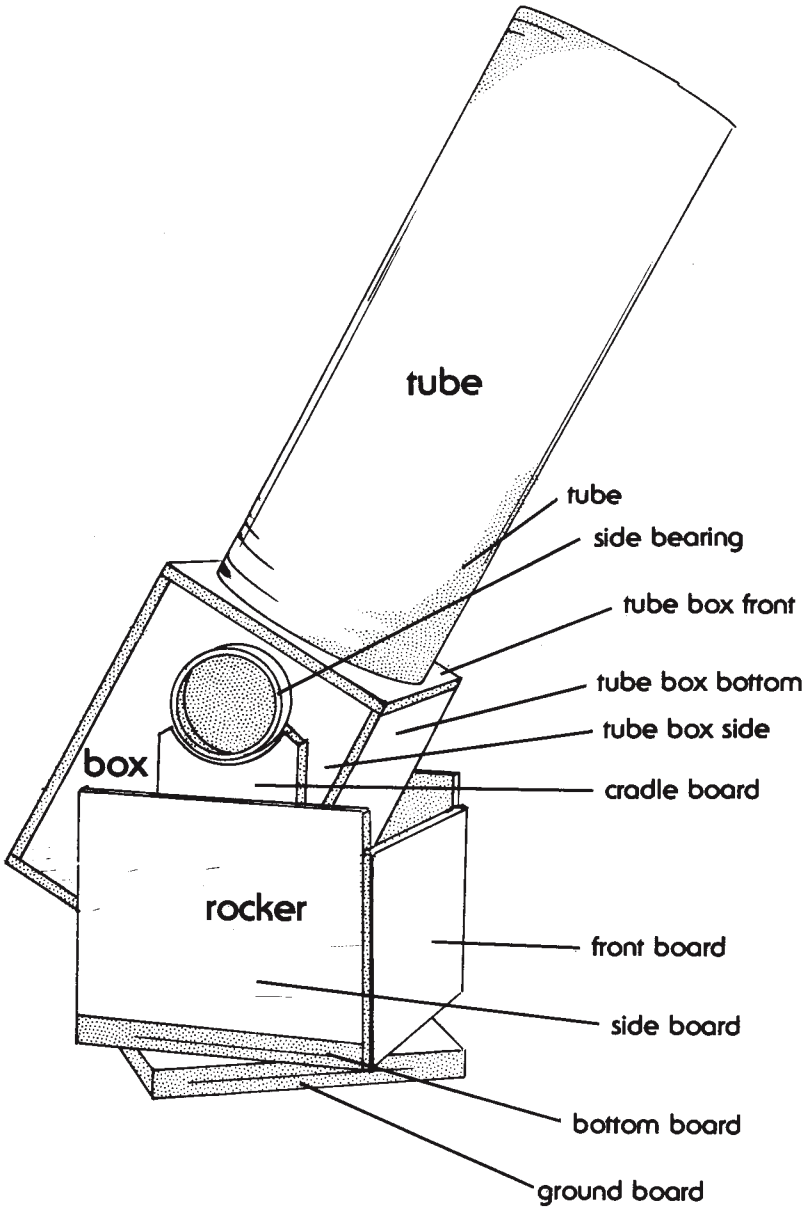
We must add several inches to the 6" of cradle boards that stick up so that we have something to attach to the inside of the side boards. Eight inches of overlap is enough, giving us cradle boards 14" long.

It is customary to make the cradle boards the width of the box, so the cradle boards are ¾" x 12¼" x 14". The width of the side boards is a couple of inches wider than the width of the box, so we'll use 15". This completes the side boards at 1" x 15" x 18".

For reasons I'll discuss later, the ground and bottom boards should be longer than this, so we'll make them 16". The dimension determined earlier was 17¾" wide, making the bottom and ground boards 1" x 17¾" x 16" and 1½" x 17¾" x 16". The height of the front board is measured from the bottom of the bottom board up to a point that is low enough to allow the telescope to point a little past the horizon, in this case 18". The width determined earlier was 17¾" making the front board ¾" x 17¾" x 18".

Last, the 3 feet can be almost any size within reason. We'll use ¾" x 2" x 2".

Parts of a Dobsonian



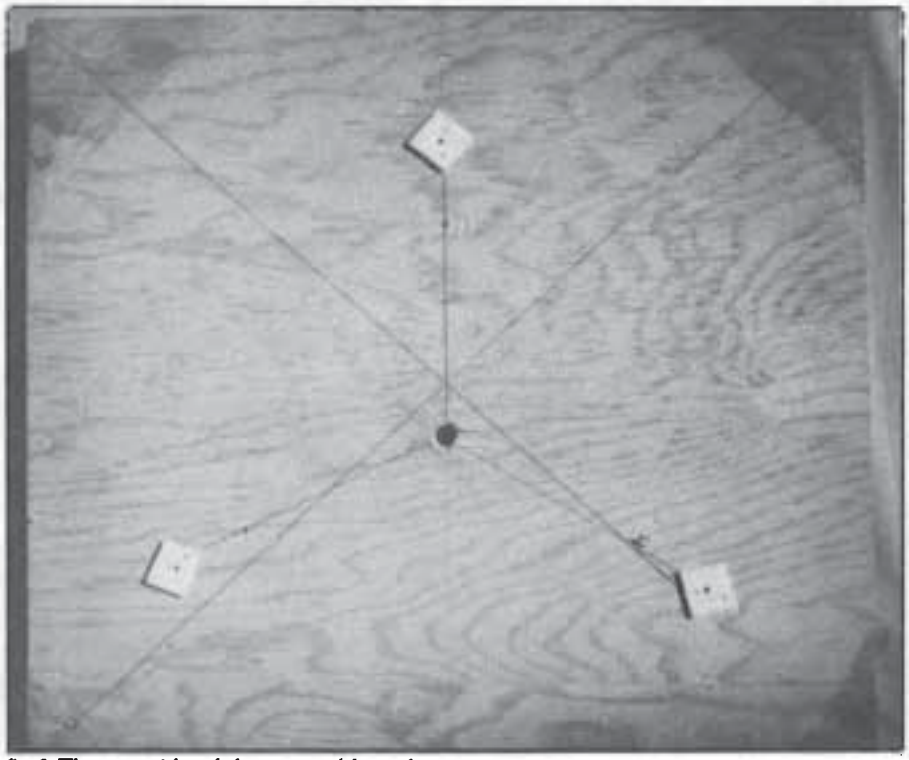


fig 3 The top side of the ground board ▲

▼ fig. 4 The tailgate for an 8" f/7

The whole thing, all the wooden parts for the 10" Dobsonian, now looks like this:

2)	¾" x 12¼" x 13-15/16"	Box top and bottom
2)	¾" x 12¼" x 12-7/16"	Box sides
2)	¾" x 12¼" x 14"	Cradle Boards
2)	1" x 15" x 18"	Side Boards
1)	¾" x 17¾" x 18"	Front Board
1)	1" x 16" x 17¾"	Bottom Board
2)	¾" x 16" x 17¾"	Ground Board
3)	¾" x 2" x 2"	Feet
1)	¾" x 10" x 10"	Tailgate (discussed later)

Construction

Don't be discouraged if you have no accurate way to cut wooden parts. If you can cut carefully with a handsaw, your only concern need be that edges to be glued are as flat, straight, and square as possible. You can touch up the edges with a wood rasp and coarse sandpaper if there are minor deficiencies in craftsmanship. Other than this, you can cut as crudely as you want and not detract a bit from the instrument's performance. Of course, the mount will then not look as nice.

Begin by gluing the double-thickness boards together. For the 10" example, only the ground boards get this. Smear the glue on both surfaces, then press them together and nail with 3 or 4 small nails to hold them tight. If you're building a large rocker that requires most of the boards to be double, buy the glue in quart containers. Pour some into a can and add a little water to thin it, then apply it with a paint brush. Tack all the boards together with little nails, making sure the edges meet properly. Stack them up and then put everything you own that is not nailed down (i.e., load on several hundred pounds of weights) on top of them and leave it overnight.

The cradle boards have to be cut out to fit your side bearings, in our example an 8½" semicircle. If you don't have access to a jigsaw, you can cut a "vee" in the top of the cradle boards with a handsaw.

You're going to glue all the joints and nail them down tight. White wood glue and galvanized nails give fine results, but waterproof resin glue and woodscrews weather slightly better.

When the boards are ready to go, start by driving 3 or 4 galvanized nails in the bottom of the ground board on each side under where the side boards will be attached. Then run glue along the bottom of the side boards and the top of the bottom board. Nail the bottom board to the side boards making sure the side boards come precisely flush to the front of the bottom board. Next, glue and nail the front board on over the ends of both side boards and the floor board. Assembling them this way holds the side boards on and insures the correct spacing between them.

Build the tube box the same way, making sure the two shorter boards (the box side) go between the two long (box top and box bottom) boards.

Nail the feet to the underside of the ground board in a triangle as shown in fig. 8. Two of them go in the corners of the front side and one goes in the middle of the back side. The ground board can now be regarded (structurally) as a triangle with its points over the feet.

The hole that will hold the center bolt isn't placed dead center on the ground board; rather it is drilled in the center of the triangle. This means you'll find you must drill the hole about an inch forward of the center of the ground board, as shown in fig. 3.

Mark the spot for the hole in the bottom board in the corresponding place in the ground board. Then check that the bottom board doesn't overhang the ground board when the two are rotated. If it does overhang (and this is part of the reason we make the ground and bottom boards a little wider than the side boards), choose a midpoint rather ▶

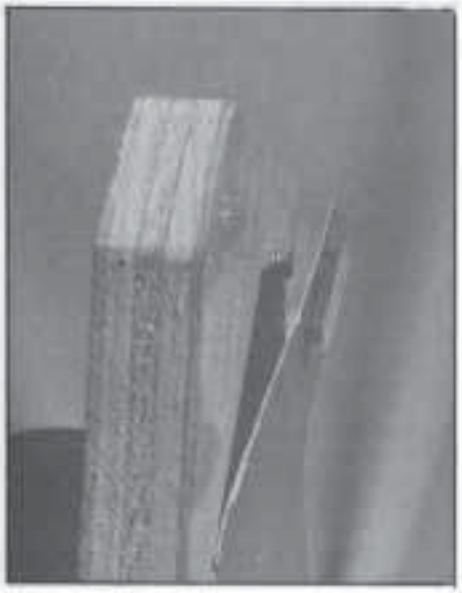


fig. 5 Detail of the masonite pad

fig. 6 The "mirror side" of a tailgate

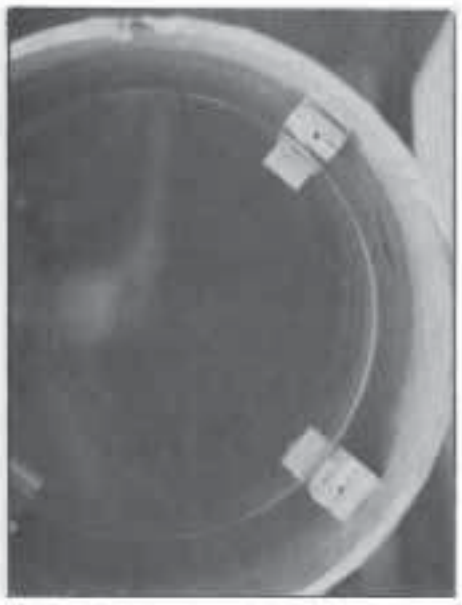


fig. 7 The four blocks holding a mirror

.n displace the center of the rocker too far oi center.

Next, you'll want to place the cradle boards so that the center of gravity of the telescope and top part of the rocker is over the hole in the ground board. To do this, move them forward of center almost as much as the holes were moved forward. (The distance would be the same except for the weight of the front board to be balanced.)

Once you've found the proper location for the cradle boards, nail them in place with small nails, without gluing, so they can be adjusted later if the telescope rubs on them. After they've been adjusted, I recommend 4 large wood screws in each to attach them solidly. Remember to countersink the heads beneath the surface of the wood.

The hole for the center bolt should be slightly undersized. The bolt itself can be forced up through the ground board and will be very tight. Alternatively, a large lag screw can be threaded into the ground board from the top of the bottom board. I would only recommend the lag screw for telescopes less than 16" because for the big scopes it's nice to be able to detach the ground board — which can be quite heavy — for transportation.

Once the tube box has been pushed over the tube and the telescope is completed, fasten them together so the telescope tube won't slip around in the box. To do this, run 2 wood screws from the inside of the tube into the box.

The Bearings

The side bearings can be made many different ways. Here's a chance to apply your imagination — anything goes just as long as it's round and smooth around the circumference. I prefer ½" wall PVC pipe cut 1" deep. Another favorite is old phonograph turntables from the scrap heap. Circles cut from wood work well if you put a metal band tightly around them. These are just a few ideas...there are many more.

Don't use circles that are too small. One reason that Dobsonians work so well is they have very large bearings. Try to keep the bearings at least 4" for an 8" scope and a minimum of 8" for an 18" scope.

Screw down whatever bearing disk you do use as close to the middle of the sides of the box as possible. It will turn on teflon pads in the cutouts in the cradle boards. Nail two small pieces of teflon on each side of each half circle in the cradle boards. To increase the friction, move the teflon pads farther apart; to decrease the friction, move them closer to the center. Use small finishing nails when nailing teflon, and make sure their heads are set below the surface of the teflon.

For the bottom bearing you'll need 3 pads of teflon about 1" square for an 8" scope, twice that area for 10" and 12" scopes, and for 16" and 18" scopes I recommend 3 or 4 square inches. These pads are placed 120° apart on a circle around the center bolt as shown in fig. 3. As a rule of thumb, the diameter of the circle should be about equal to the o.d. of the tube.

The points of the triangle formed by the teflon line up with the feet, and the teflon pads must lie inside the feet triangle. If you wish, you can put 3 small pieces of teflon between the large ones for extra support. However, you must hit these with a hammer so they aren't as high as the 3 main pads. (These secondary pads keep the telescope from rocking off the main pads when the telescope is being moved when it's pointed at objects near the zenith.) It's important that you put the teflon on the top of the ground board, not the bottom of the bottom board. This will keep dirt off the face of the teflon. (You can play with the canonical Dobsonian design a lot, but altering this is heresy!)

The formica bearing surface must, of course, contain a circle large enough to cover your triangle of teflon pads. There are two ways to apply the formica to the bearing: One is to use a formica-topped sink cutout, the other is to glue plain formica to the bottom of the bottom board.

If you glue the formica, lay it down on the glue covered surface of the bottom board and lay another piece of wood on top of that making a sandwich with the formica in the middle. Then put about two hundred pounds on it overnight.

Do not oil, grease, or wax the bearings. This always makes them work terribly. There is a lot of technology in a piece of teflon, so don't ruin its performance with unnecessary grease.

Every now and then the teflon will require cleaning. This is best done with a knife blade; just scrape off any foreign material that's built-up on the teflon.

Larger Scopes

For telescopes larger than 14", some fundamental changes are made in the tube design due to the increasing weight of the scope and the need to properly support the main mirror. Other than what follows, however, the procedure for building a big Dobsonian is the same as that discussed for smaller scopes.

The major change (which you will have already wondered about if you read part I of this article) is that the box around the tube extends all the way to the end of the telescope. (I've seen telescopes as small as 10" built with the full-length box, but I think it's unnecessary for telescopes less than 12" or 14".)

Why the change? First, the tube has to be kept round, especially if it's a paper tube. An 18" or 20" concrete form tube can be very sturdy (often they come with a ½" wall), but if it's not properly supported, it may bend under its own weight. Following are a few ideas:

- To keep the front end round, I recommend a plywood ring screwed inside or outside the tube. This is not necessary but it's a good idea in the long run, and it looks good, too.
- The tube box can have a plywood front, cut to the same i.d. as the o.d. of the tube, for more support. This looks good, too.
- Even more important are plywood supports on the inside of the back of the box (see fig. 9). Cut these scrap corners with a jigsaw to fit the inside of the box and the o.d. of the tube. These also serve to reinforce the box, so nail and glue them down tight.

Sometimes it's desirable, usually for ease of transport, to be able to separate the tube from the box. Whatever you do, don't make the inside of the box any smaller than the o.d. of the tube or you'll never be able to remove the tube — the end support in the box should be made to hold the tube just snug. To separate the tube and the box, make the inside of the box a little bigger than the o.d. of the tube. Then put 4 pieces of teflon inside the front of the box where the tube rides. This will hold the tube snug and allow you to separate at will.

Earlier I recommended an 18" tube for a 16" mirror if the tube is a poor conductor of heat. This generally works well. If, however, the telescope is to be permanently mounted, a larger tube may be justified because the extra weight doesn't have to be carried around. For telescopes in the 24" range, I'd recommend a 30" tube with the inside insulated with styrofoam.

Mounting the Main Mirror

For smaller scopes, a standard homemade or commercial cell can be used provided it fits the tube. If the tube is too large, washers can make up the void between the cell and tube. Make sure the mirror is not fastened in the cell too tightly or it will be warped.

For those wanting a simpler method of mounting a mirror, I recommend the method that uses what Dobsonian builders call the tailgate. This method is used on most small Dobsonians.

The back of the mirror rests on 3 points providing collimation and is centered by four blocks of wood. Four stops protruding from the centering blocks keep the mirror from rolling down the tube (see fig. 7). First you need to build a tailgate. Cut a square from a piece of ¾" plywood. Make the side length 2" less than the i.d. of the tube. Cut off the corners so it fits inside the tube.

Obtain 3 bolts 1" long with a diameter anywhere from ¼" to ½" (it doesn't matter). Mark three points on the tailgate for the tailgate bolts 120° apart at a distance from the center equal to 0.7 times the radius of the mirror. For a 10" that would be 0.7 x 10/2 = 3.5. Drill the holes smaller than your tailgate bolts and thread the bolts right into the wood. The wood will hold the bolts tight for many years.

The mirror should not sit directly on the hard tips of the bolts or it may be broken. It is best to cover the bolts with a soft yet rigid material like masonite, but you can't just attach the masonite directly to the bolts or collimation would prove impossible. Instead, glue the masonite to a piece of heavy construction paper or light cardboard (such as cereal boxes are made of) cut to fit the triangle formed by the bolts. Staple the construction paper to the middle of the tailgate (fig. 6). The construction paper allows the masonite to move up and down freely, but holds it right in front of the bolts (fig. 5).

The blocks of wood that center the mirror must not be too thick or the mirror won't fit between them, and not too small or the mirror will rattle around and not sit in the center. For a 10" mirror in a 12" tube, 1" thick blocks sanded a bit on their tops are just right. When they are right, they'll allow the mirror to sit freely between them, but it won't rattle back and forth.

Each block has a stop to keep the mirror from falling down the tube. The stops should be just far enough from the face of the mirror so it cannot be pushed up against them by the tailgate bolts and not so far away that they can't perform their duty.

To assemble the whole arrangement, screw the four blocks of wood to the tube, running the screws through the tube into the wood. Make sure they lie equal distances from the end of the tube and far enough in to accommodate the thickness of the tailgate board. Fasten the tailgate in place by running screws through the back of the tailgate into the back of the four blocks.

fig. 8 The bottom of a ground showing feet

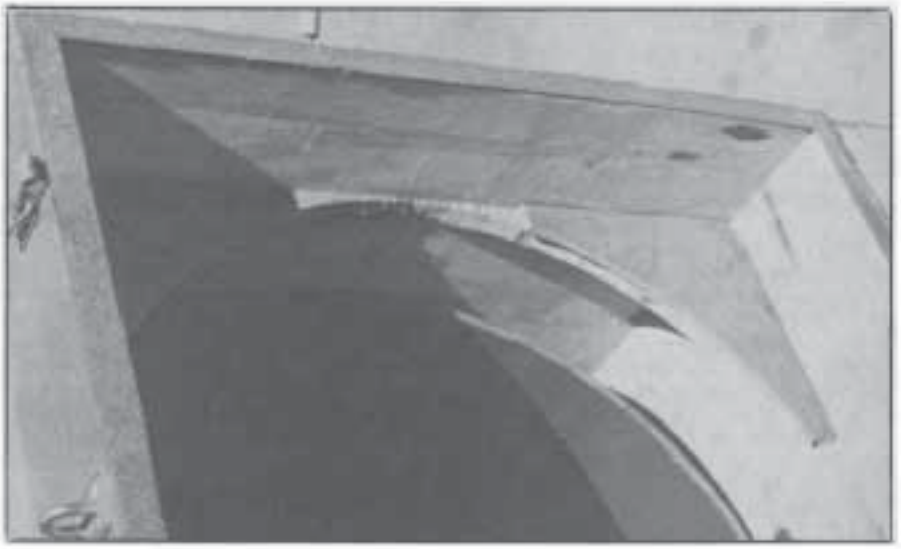


fig. 9 Tube supports in the back of a box

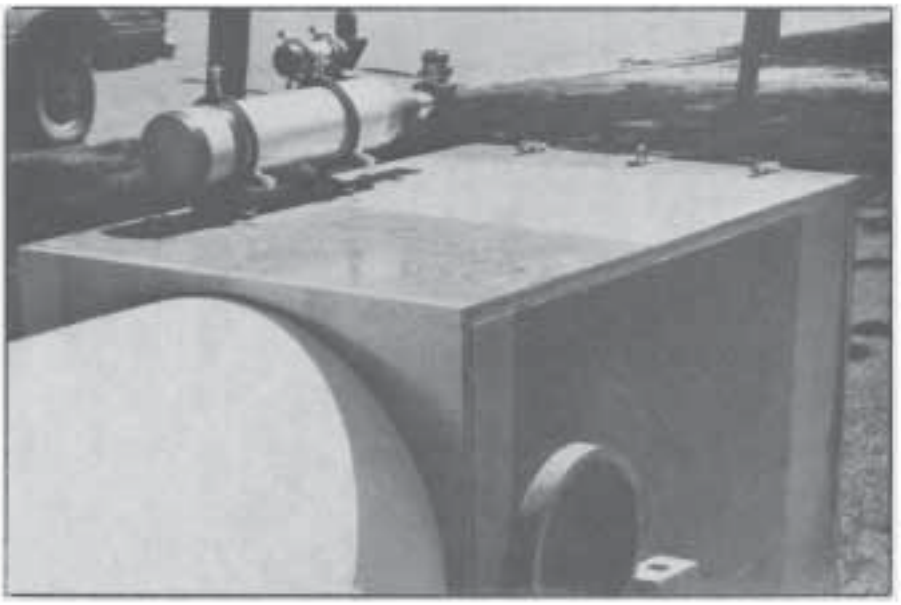


fig. 10 18" rocker and box

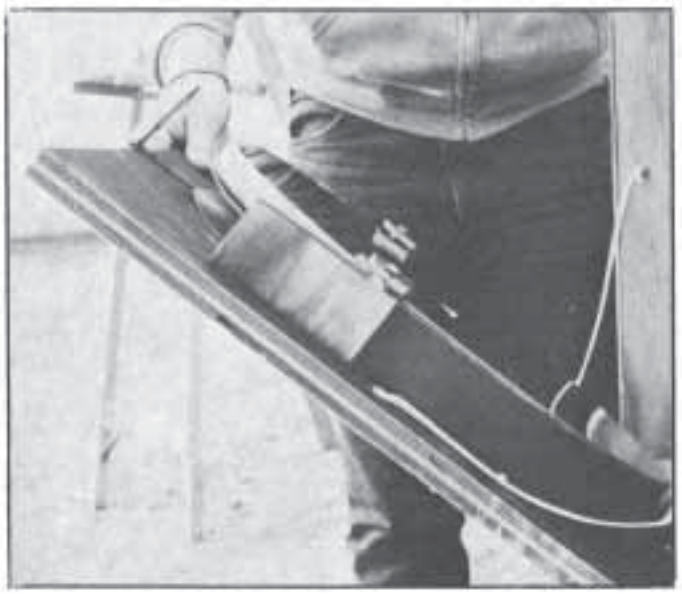


fig. 11 Tailgate of an 18"

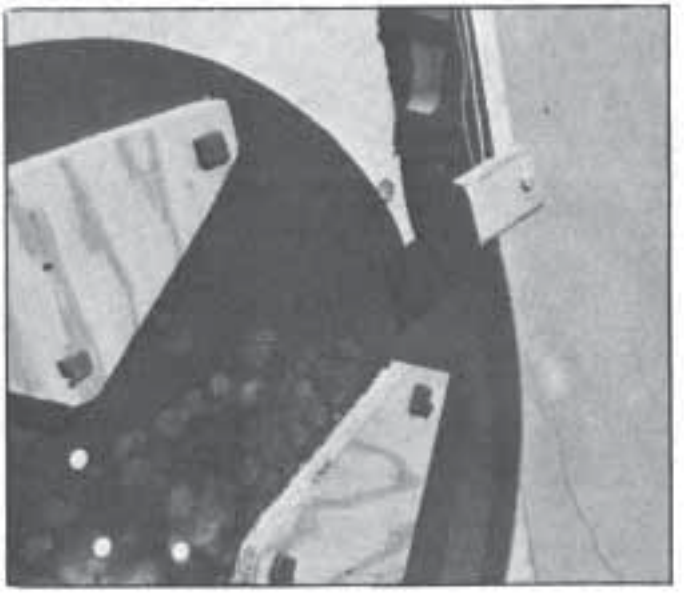


fig. 12 Triangles, strap, and ears

◄ Dobsonian

Large Mirrors

How would you mount an 18" diameter mirror 1" thick without warping it? When the problem first arose for me, I put that question to John Dobson. He answered: "Hang the mirror freely in a sling with its back resting on a 9 point flotation." It works.

To construct this arrangement for a Dobsonian, you must build a tailgate on the end of the tube box. This tailgate is cut to the outer dimension of the box and is attached to the underside of the box with hinges. On the top, an ordinary hardware store-type hasp arrangement holds the tailgate snugly against the box and will also accommodate a lock.

To find out what a 9 point suspension is, obtain a copy of *Amateur Telescope Making, Book I.* On page 234 you'll find a diagram laying out the distance relationships for a 9 point suspension. Draw out your own full-size diagram directly on a piece of construction paper cut in a circle with the same diameter as your mirror. From the diagram you'll be able to tell how big to make the triangles that support the mirror.

Be sure and cut them a little larger than their geometric size. I've used ¾" plywood for the triangles, which seems a bit crude, but it offers a very sturdy and vibration free support. The triangles must be marked with the exact places the tailgate bolt will touch and where the points supporting the mirror will be placed. One-half inch square pieces of masonite glued to each corner point of the triangles provide support for the mirror.

Using the diagram again, lay out the 3 points on the tailgate for the tailgate bolts. ⅝" x 1" bolts do nicely for the tailgate bolts. Drill the holes smaller than the bolts and thread the bolts firmly into the wood. Now attach the triangles to the construction paper diagram exactly where they are drawn on the paper — two or three thumb tacks from the underside will suffice. The paper holds the triangles in place correctly but still allows them to rock freely (fig. 11). Attach the construction paper to the tailgate with its center point at the center of the tailgate. Doublecheck that each triangle's center is directly over a tailgate bolt and that each triangle rocks freely on its bolt.

The sling should be at least as thick as the mirror. It should run around 180° of the mirror — and no more. I've had good luck with automobile seat belts. I'm sure there are as many different ways of attaching the sling to the tailgate as there are tailgates, but I prefer to attach it to a 4" length of plywood nailed and glued to each side of the tailgate (fig. 12). I call these the uprights. The strap is secured down on the inside of the uprights.

Be sure there is enough room to allow the mirror to slip between them. Also remember in planning them not to place them too far apart or make them too thick or the tailgate won't close.

Little wooden tabs I call "ears" screw down to the top of the uprights and prevent the mirror from falling forward (fig. 12). The ears turn out of the way to allow the mirror to be inserted and removed from the telescope. They should be constructed in such a way that when they are turned aside, the box will hit them if you forget to turn them back in front of the mirror (easy to forget in the dark).

Since the mirror can be put into and taken out of the telescope for each observing session, you'll need something to carry it in. Make a sturdy wood carrying box for it.

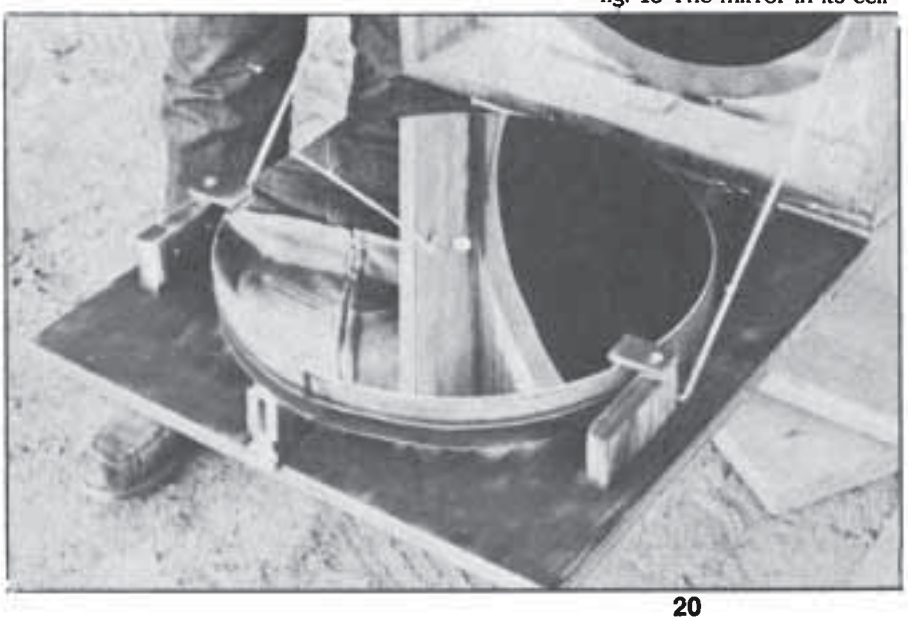
It is becoming popular to combine the support system and the carrying box in one (see, for example, the scope on page 32 of TM#4). This way the mirror is never touched when it is loaded and removed from the telescope. If you go this route, plan very carefully or the cell won't fit when you close the tailgate. Also, you'll have to come up with a clever way of "hanging" the box so it will sit firmly on the tailgate's bolts.

I don't know just exactly what size and thickness mirror should go on 18 points, but it's customary for thin mirrors over 18" to go on 18 points. Dimensions for 18 point suspension systems can be found in *Amateur Telescope Making Book I.*

More Dobson Technology

If you wish, you can build a simple slide focuser and diagonal spider for about two dollars. This means, if you're short of funds, that you can have a bigger primary mirror.

fig. 13 The mirror in its cell



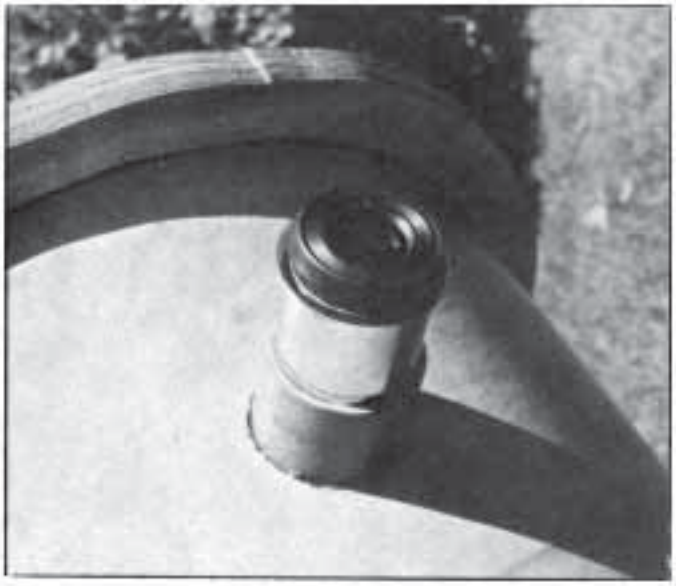


fig. 14 A simple focuser

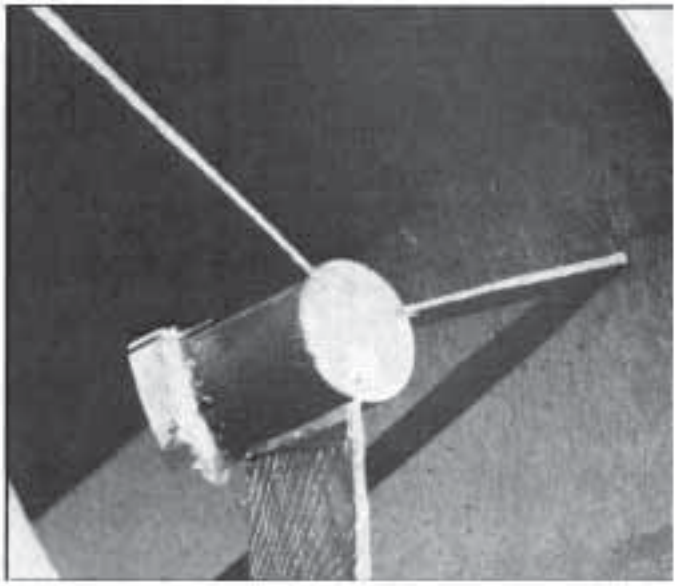


fig. 15 Wooden diagonal support

For the focuser you'll need a 4" length of 1½" o.d. chrome-plated brass tubing from a drain line basin. (This can be found in any plumbers scrap box or a hardware store.) Next, you need a 1½" i.d. heavy-wall paper tube from the inside of the plastic bag rolls found in the produce department of supermarkets, and a piece of masonite 3" x 4".

Cut a hole in the masonite equal to the o.d. of your brass tube. Cut 2" off your paper tube, stripping out a couple layers of paper if necessary, until it fits smoothly over the brass tube. Glue it to the masonite carefully centering it on the hole. You install this insty-focuser in the telescope by gluing the masonite to the tube (fig. 16).

The draw tube doesn't fit standard 1¼" eyepieces, but if you wish it to, you can make a reducer. The 1½" tube does fit surplus 7 x 50 binocular eyepieces — good for RFT work — nicely. If you are worrying about fine focus with a slide draw tube, I assure you it's easier than a rack and pinion.

The spider is equally easy (fig. 15). Obtain a wooden dowel rod about 4" long that's smaller than your diagonal. Cut one end off at a 45° angle with a saw, and on its sides, cut three grooves 3/16" deep and 120° apart. None of the grooves should face the eyepiece. Use cedar wood for the legs; it's available as shingles intended for the first layer of a roof. Cut them about 1½" wide. Force fit the thin edge into the grooves, then cut the shingles to fit tightly in the tube. The diagonal can be glued to the block with silicon rubber. Be sure to paint the spider black before gluing on the diagonal.

Some Words of Caution

If there were just one caution I'd give to anybody building the Dobsonian design it would be: Think twice about modifying it. The way they are built and the sturdy performance is no accident.

For example, if you choose (for whatever reason) to omit the front board on the mount, the performance will suffer greatly even if you support the side boards with fancy triangular supports from the side. (This is what the original Dobsonian designs looked like; today's evolved from it many years ago.)

Another variant I see often is sideboards made with hardwood boards set in a triangle or crossed and attached at their middles. This can look very sexy, but in all those I've seen, it's been at the expense of optimum performance.

The proper side bearing diameter and ground board thickness is also important. Keep them thick — there should be no flexure in either.

Another frequent mistake is the use of ball bearings. Ball bearings are meant for going 5000 r.p.m., not 100 revs. per night. Without the just-right friction of teflon on formica, the telescope just moves and moves from sundown till sunup, and half your observing time is spent holding the scope still and refinding objects.

The 4" pictured in this article suffers from this affliction. I thought I could get away with the azimuth ball bearings because the scope is so small, but after observing for half an hour with it, I find myself biting my fingernails out of frustration — the same way I did before I built my first Dobsonian mount. I guess I'm just spoiled.

Bob Kestner
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Concord, CA 94518

■

fig. 16 Focuser from inside the tube

fig. 17 A very portable 4" f/7 telescope

Telescope Design for

by
Robert Provin & Brad Wallis

It's too bad that most Newtonian reflectors used for astrophotography were intended primarily for visual use. Standard commercial Newtonians are designed to satisfy a wide range of basically visual applications — as well as keep the manufacturing costs as low as possible. Amateur astrophotographers typically purchase or build a Newtonian modeled on these commercial specs and then expect it to function as a photographic instrument. But just as a good planetary reflector departs strongly in design from an RFT, so must a photographic Newtonian depart from the basic visual model.

The primary design problems in building a photographic Newtonian are the size of the coma-free field, f-ratio, diagonal size, the circle of full illumination at the film plane, and mechanical design considerations. We're assuming here that our telescope will be used with a 35 mm camera, and that the image will be brought to the Newtonian focus outside the tube.

Selecting the optimum f-ratio for a photographic reflector involves a compromise between the size of the photographically coma-free field and photographic speed. The optical nature of the paraboloidal mirrors used in Newtonians means that enlarging the coma-free field results in a longer f-ratio, or reduction of photographic speed. The reason for this is that the diameter of the coma-free field is determined by the angle of convergence in the cone of light from the primary mirror; this in turn is a function of f-ratio. Smaller focal ratios have greater angles of convergence and smaller coma-free fields.

In fact, all Newtonians of a given f-ratio have the same diameter coma-free field. Thus a 6" f/5 Newtonian and the 100" f/5 Hooker telescope both have approximately one inch diameter coma-free fields as measured at the film plane. The difference, of course, between these two instruments lies in image scale. While one inch at the film plane of the six inch telescope covers 110 minutes of arc, at the film plane of the Hooker telescope, it covers only 6.5 minutes! The accompanying table illustrates the compromise between coma-free field and f-ratio quite clearly.

FOCAL RATIO	4	5	6	7	8
FIELD SIZE: (diameter in inches)	.5	1.0	1.7	2.6	4.0

In selecting the optimum f-ratio, your prime concern should be photographic speed. However, it's also important to take into account the relationship between the coma-free field and the film format. Since most amateurs use 35 mm film and cameras, an f-ratio producing no coma over the short dimension of this format (24 mm x 36 mm) is a minimum requirement. While an f/5 paraboloid just meets this requirement, an f/6 system covers all of the frame and shows no coma.

These focal ratios give the fastest photographic speeds normally possible for a simple Newtonian using the 35 mm format. Amateurs with faster Newtonians can still use their instruments effectively when shooting objects confined to the center of the field, and for larger objects, they can use an aperture stop to enlarge the usable film area at the expense of speed. Because aperture stops reduce the size of the main mirror relative to the secondary mirror, they achieve the added benefit of enlarging the circle of full illumination at the film plane.

The area of full illumination is another primary concern with deep-sky photographic reflectors. It should be as large as possible. The size of the circle of 100% illumination is determined mainly by the inside diameter of the focusing tube and by the size of the secondary mirror. The standard 1¼" i.d. focusing tubes found on most visual reflectors vignette the cone of light reaching the film plane. To illuminate the 35 mm format fully (regardless of the size of the secondary), a 2" i.d. focuser must be used because the diameter of the focusing tube must be larger than the diagonal of the film format used.

The focuser should, in addition, have as low a profile as possible. This allows moving of the film plane closer to the secondary mirror, thus narrowing the cone of light that the secondary must intercept from the primary mirror. Of course, this confers another benefit: a smaller secondary can be employed while illuminating an equal film area.

The requirements for a good photographic focuser aren't met by most commercially manufactured units. Of the many 2-inch focusers available, most have very high profiles and are designed primarily for 8" and larger telescopes. On our telescopes, we solved the problem by modifying Telescopics' 2" i.d. Sky Micro Giant focuser. This focuser is designed for telescopes of eight inch aperture and larger and is approximately 5.5 inches high when racked all the way in. By cutting it down, machining the base flat, and mounting it on a U-channel base, we reduced it to just over 2.5 inches. (With careful machining it would be possible to reduce the profile to a mere two inches, thereby producing a very efficient focuser!)

An additional modification includes a set screw with a teflon tip. Once adjusted, the focuser can be securely locked in place without damaging the focusing tube. Both modifications can be done on most commercial units.

The size of the secondary mirror is probably the most important factor in determining how large the circle of illumination will be at the film plane. Most commercial and amateur-made reflectors, because they are designed for visual use, are equipped with secondaries that are considerably undersized. While adequate for visual use, these smaller diagonals fully illuminate a circle that is only about ½ inch in diameter at the film plane. With 35 mm film, a minimum value of one inch of full illumination will give better results. The accompanying nomograph gives the minimum diagonal sizes for popular aperture and focal ratio combinations that fulfill this requirement. The

Deep-Sky Photography

Commercial telescopes have been designed primarily for visual use. For astrophotography you've got to have something better.

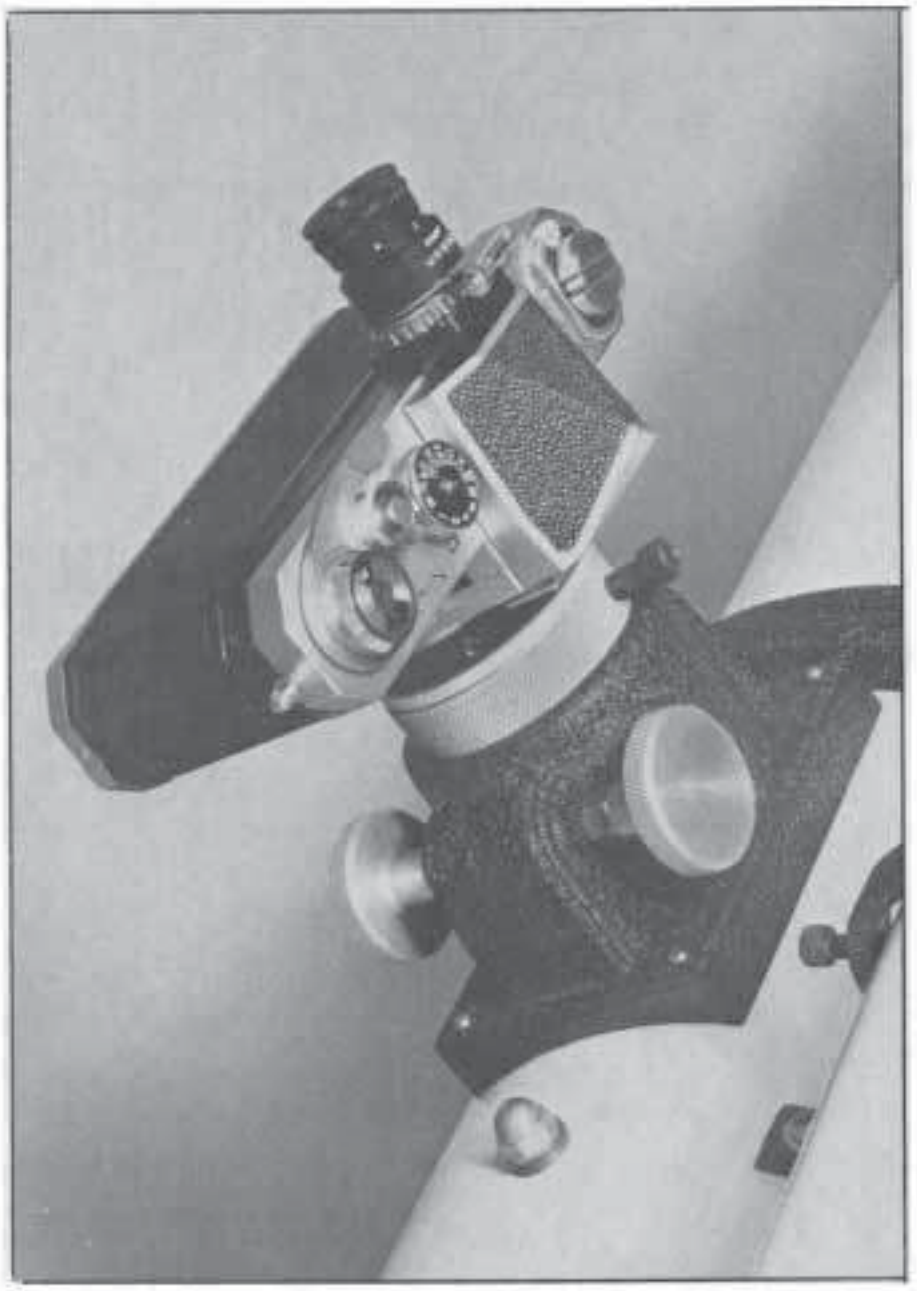
values given on the nomograph assume a focuser profile height of not more than 2.5 inches, and they fully illuminate a one inch diameter circle with only 30% to 35% loss of light at the very corners of the frame. This amount of vignetting is only slightly detectable when high contrast emulsions (like Kodak's 103a-emulsions) are used and is virtually undetectable when color films are used.

One of the most critical elements in the design of a photographic Newtonian is the tube. Most commercial and many amateur instruments are equipped with tubes that are too short and lack sufficient strength. To protect against stray light during long exposures, the tube should extend about 1.5 apertures past the position of the focuser. This provides adequate protection without seriously adding to vignetting of the field.

Tube strength is a most important part of photographic reflector design. Bakelite, cardboard, and particularly fiber glass tubes are often the primary contributor to the astrophotographer's worst enemy, flexure. As telescope tubes, these materials simply don't have the rigidity to maintain optical alignment within the tolerances required during long exposures. The best solution to this problem is to use a ring-braced aluminum tube with a wall thickness of 1/16" to 3/32". An aluminum tube will provide adequate strength and will be relatively light in weight.

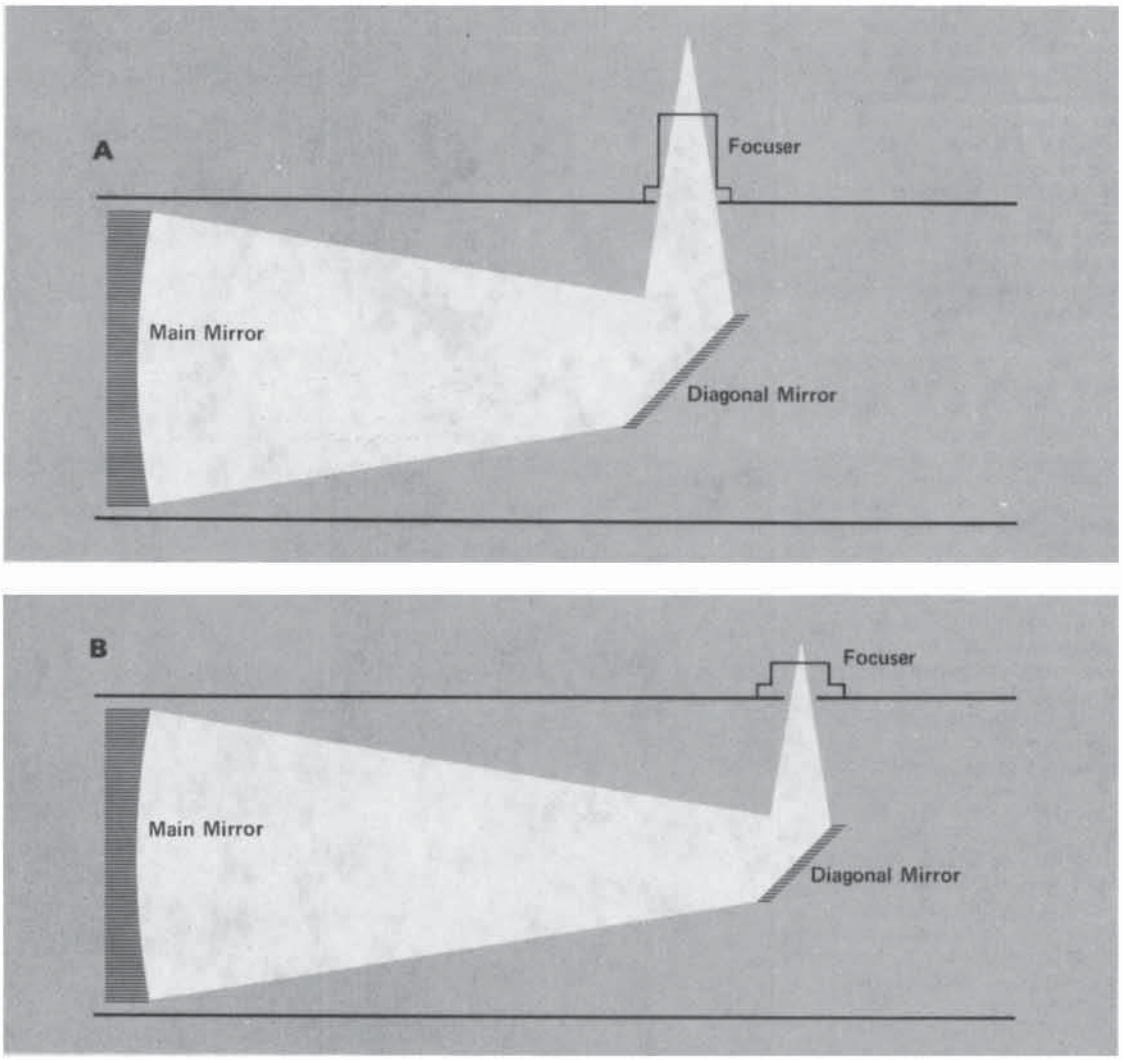
Finally, the optical supports merit consideration. While most commercial and amateur-made main mirror supports are rigid enough for astrophotography, secondary mirror supports and spiders are usually seriously lacking. After poor guiding and tube flexure, sagging of the secondary mirror is probably the most common cause of trailed star images on astronomical photographs.

One remedy is to build a solid spider support. The traditional four-vane type with heavier-than-normal construction is adequate. The support vanes, in particular, should be made as stiff as possible without causing undue diffraction. (By no means should the vanes be flexible unless they are made of stainless steel or some other high



Modified Telescopics Sky Micro Giant focuser with Nikon F camera.

After poor guiding and tube flexure sagging of the secondary mirror is probably the most common cause of trailed star images on astronomical photographs.



The relationship between focuser height, diagonal size, and the cone of light from the main mirror. Telescopes A and B are optically identical — but note how a larger diagonal must be used in B.

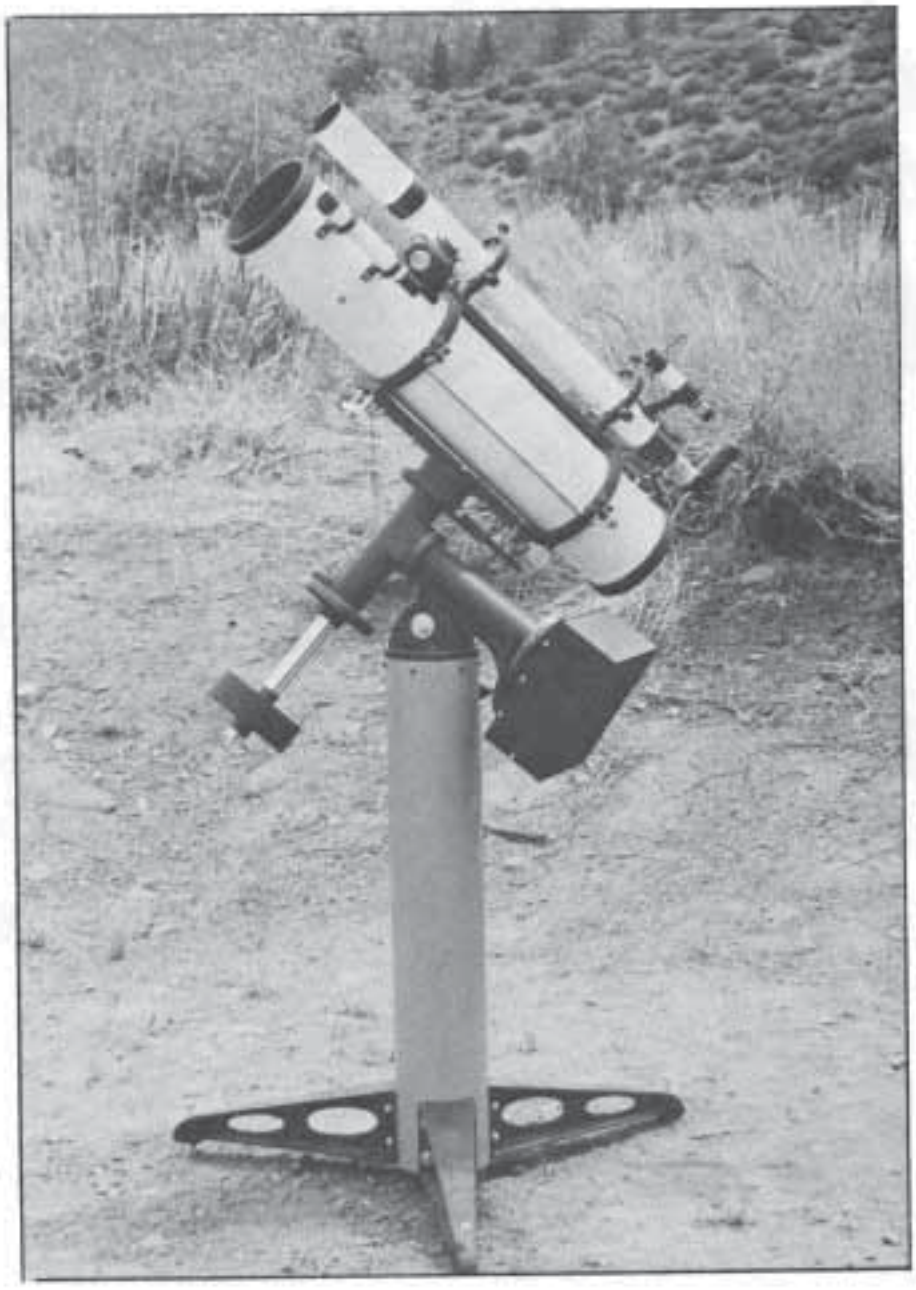
tensile strength material.) Of the commercial units, those manufactured by Kenneth Novak Co. are highly recommended.

Spider supports should be mounted under high tension which may necessitate some additional support — already recommended — for the tube. The best way to accomplish this is by adding a support ring machined to fit inside the tube at the point where the spider is mounted. You can then put extremely high tension on the vanes without distortion or damage to the tube.

Some design aspects aren't directly related to the photographic telescope itself: namely, tube supports on the equatorial mounting and the camera-to-telescope coupling mechanism. Although a sufficiently thick-walled aluminum tube might give adequate rigidity to the optics, extra strength can be achieved with a well-designed tube cradle. The cradle should span as much of the distance between the focuser and the mounting bolts for the main mirror as possible. By making the cradle longer than normal, the probability of tube flexure is greatly diminished. If the cradle is the type that employs tube clamps, still greater support can be realized by adding struts spanning the distance between the clamps.

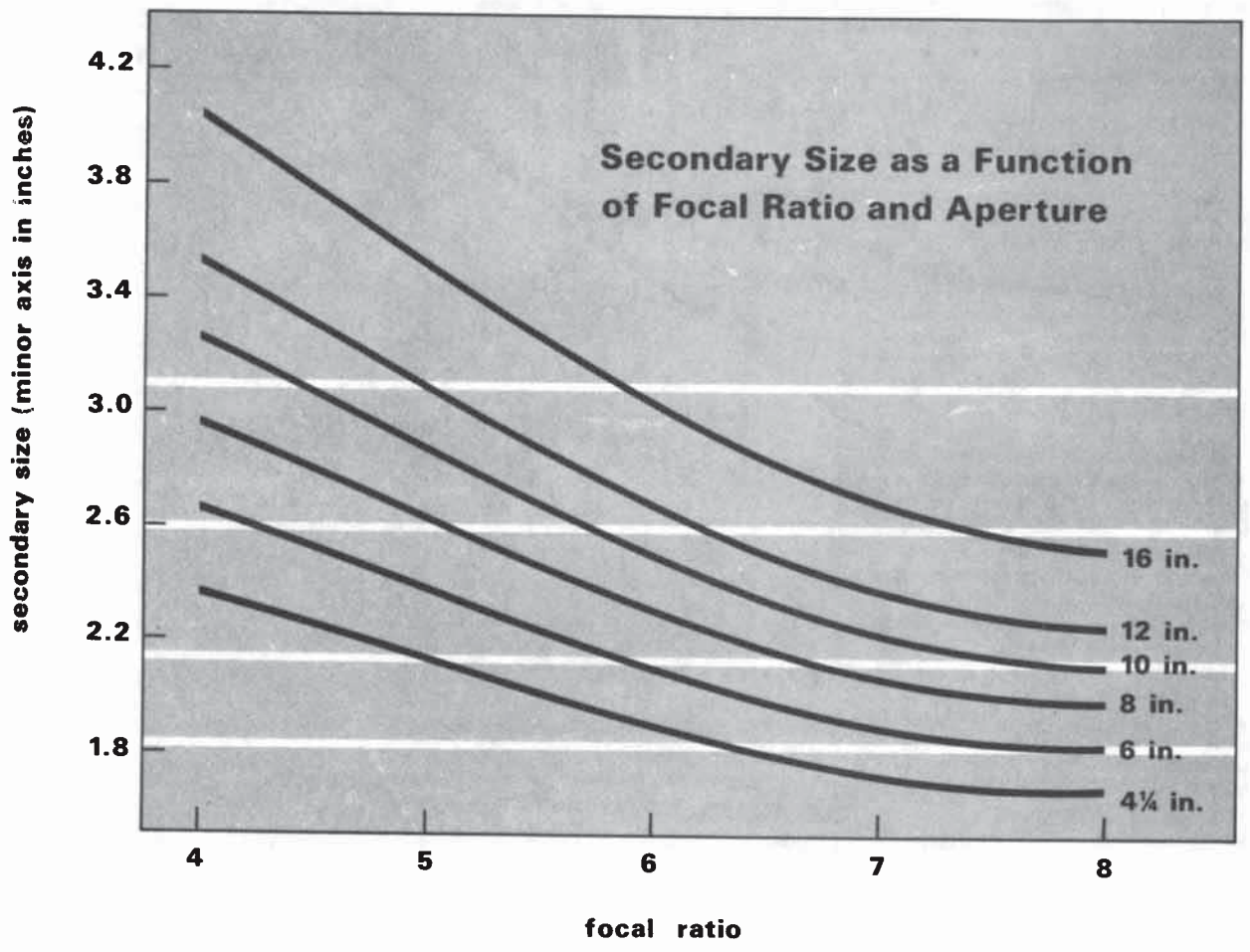
The coupling between the camera body and the focuser is extremely important. Tightness of the bayonet or screw mount on the T-adaptor is essential — but sometimes overlooked — while the camera to focuser flange (2 inch o.d.) should be securely fastened by two set screws 90° apart. It's important to remember that a photographic telescope is only as good as its weakest component. Don't let a well-designed and carefully constructed tube assembly get wasted because of less-than-adequate tube supports and camera coupling!

Quite often the telescope is the weakest link in the chain of sophisticated equipment used by amateur astrophotographers. While much time and money are spent in the selection of ►



Mr. Provin's 6" f/5 astrophotographic reflector.

The coupling between the camera body and the focuser is extremely important.



"Coma-free" field is defined as "not objectionable in an 8x enlargement of the negative."

◄ astrophotography

M-45 photographed with the 6" f/5 reflector stopped down to f/6 for better field coverage.

cameras, darkroom equipment, and other related accessories, many amateurs simply don't invest the same effort in the telescope. Although instruments designed for general use can and do produce some excellent work, a telescope designed specifically for deep-sky photography more effectively uses the film that we so treasure after a long night at the telescope. A well-designed photographic telescope can greatly improve your chances of obtaining perfect sharp round star images on the film, and — just as important — will effectively allow twice to three times the film area imaged by most commercial compromise designs.

In the final analysis you must ask yourself "Would I use an RFT to study the planets or the Moon?" The answer is: "No, not for the very best results!", so why take photographs with a telescope that was only designed to look through?

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■

Fairborn Observatory: It's Equipped for Photoelectric Photometry

by Russell M. Genet

Photographs by Daniel Hollingsworth

My interest in astronomy dates back to my childhood, when we used to sleep out in the summer and my father would point out the various constellations and explain some of the vast distances involved. Nevertheless, except for a two-inch refractor I assembled while in junior high school, my astronomical activities had been restricted to reading. I recently bought a place in the country, and the dark night skies motivated me to get out of the "armchair" mode and plan and construct what I've always wanted, an observatory of my own.

While I'm certainly interested in casual observing, I wanted to make observations that would be of some use in advancing astronomical knowledge, however slight. In a small number of fields, amateurs can make useful contributions; considering my background in electronics, I felt that photoelectric measurements of variable stars and lunar occultations would be a fruitful area for me to explore (see references 1 and 2). The telescope, observatory, and supporting equipment were designed or selected with convenient stellar photometry in mind. The problem was to maximize usefulness on a limited financial budget and tight schedule.

Requirements

The requirements for a telescope suitable for photoelectric measurement of the faint light from stellar sources are somewhat different from those required, for instance, for nebular photography or observing visual binaries.

A reflector is preferred since observations in the ultraviolet (UV) part of the spectrum are desirable. Aluminized reflecting optics, especially, have high ultraviolet efficiency, while the lenses of a refractor, due to the high absorption of ultraviolet light, have low UV transmission and are not suitable.

Although it's not a necessity, long focal length is helpful because it gives a large image scale (arc-sec/mm) in the focal plane. This eases the construction of small aperture diaphragms in the photometer head and the centering of stars in the diaphragm later during observing. A high f-ratio is also helpful because with a slowly diverging beam, there is more space to mount the diaphragms, filters, and other apparatus in the photometer. Very successful photometers have been built for telescopes with low f-ratios, however. While the on-axis image must be of good quality, off-axis images need not be.

Photoelectric observations of stars require that the image being measured stay reasonably centered in a very small diaphragm in the photometer for as long as several minutes. It is also highly desirable that the mechanical disturbance involved in changing the filters, diaphragms, etc. on the photometer not move the star in the diaphragm. (The diaphragm can be as small as 20 arc-secs projected on the sky; the displacement of the image should be much less.) Placing the photometer head near the intersection of the axes can help by reducing the lever-arm in making adjustments, and electrical correction in R.A. and Dec. are helpful. While electrical actuators could be used to operate the photometer's functions (for a "hands-off" mode), the best solution is to build a solid mounting.

The mount — rigid, massive, and carefully aligned — must also have an accurate and smooth drive. Another requirement is that the photomultiplier tube and filters be carefully selected so that observations will be compatible with previous observations. The UBV (ultraviolet, blue, visual) system defined by Johnson and Morgan (ref. 3) has been widely used, and observations that conform closely to this system are most likely to be useful. Furthermore, the UBV system uses the readily available and relatively inexpensive RCA 1P21 or 931A photomultiplier tubes.

Finally, the entire system would have to be easy to operate, suggesting a permanent installation. Described below is the telescope, observatory, and equipment I felt that best met these requirements, given that I was working with a limited budget and schedule.

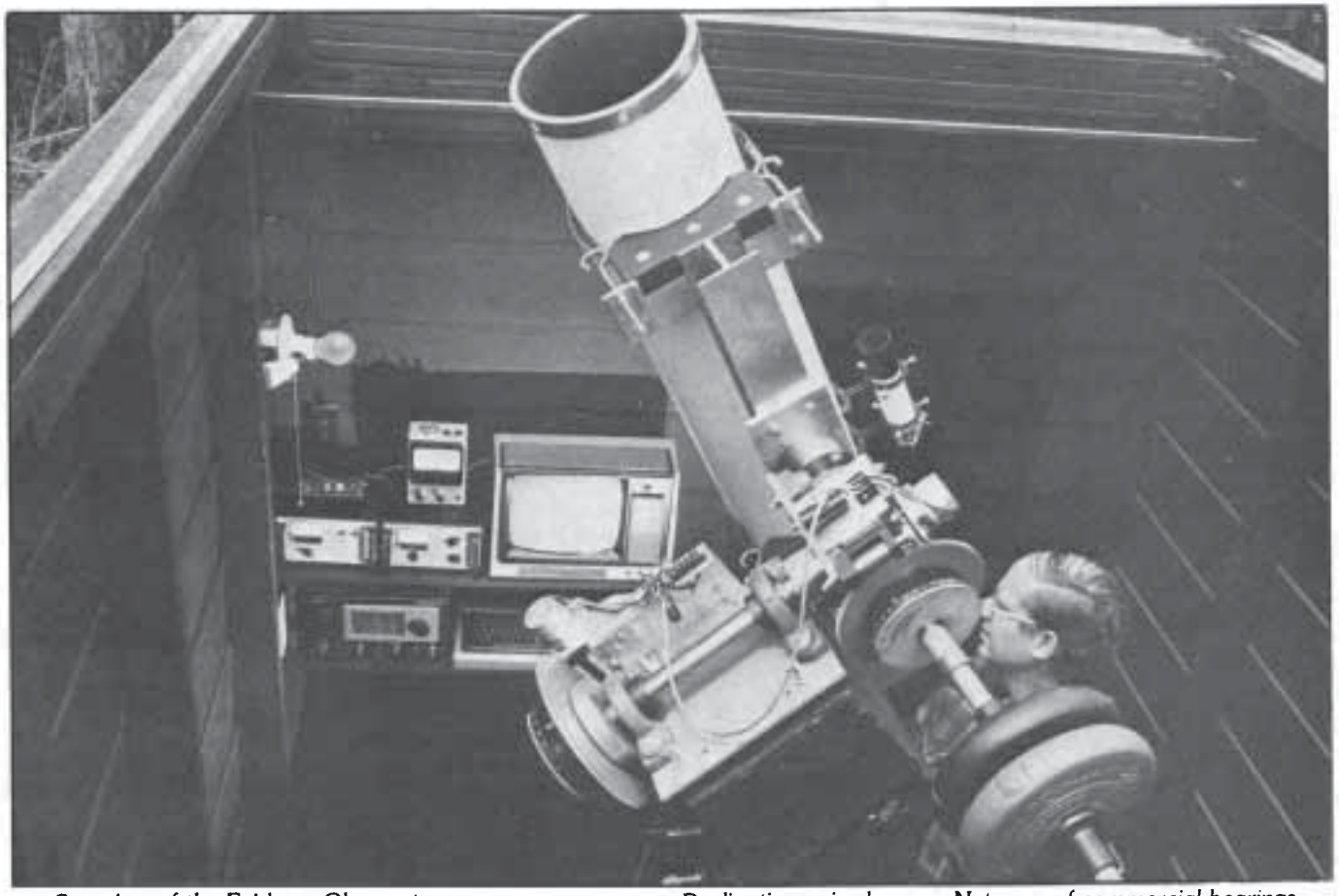
Telescope

For my telescope I chose a Cassegrain reflector. It seemed to best meet the requirements of reflective surfaces, long focal length, and high f-ratio. Stray light or sky light around the secondary can be a serious problem with Cassegrains, so tight baffling is used. In other applications such tight baffling, which reduces the off-axis illumination, might be objectionable, but not in this case.

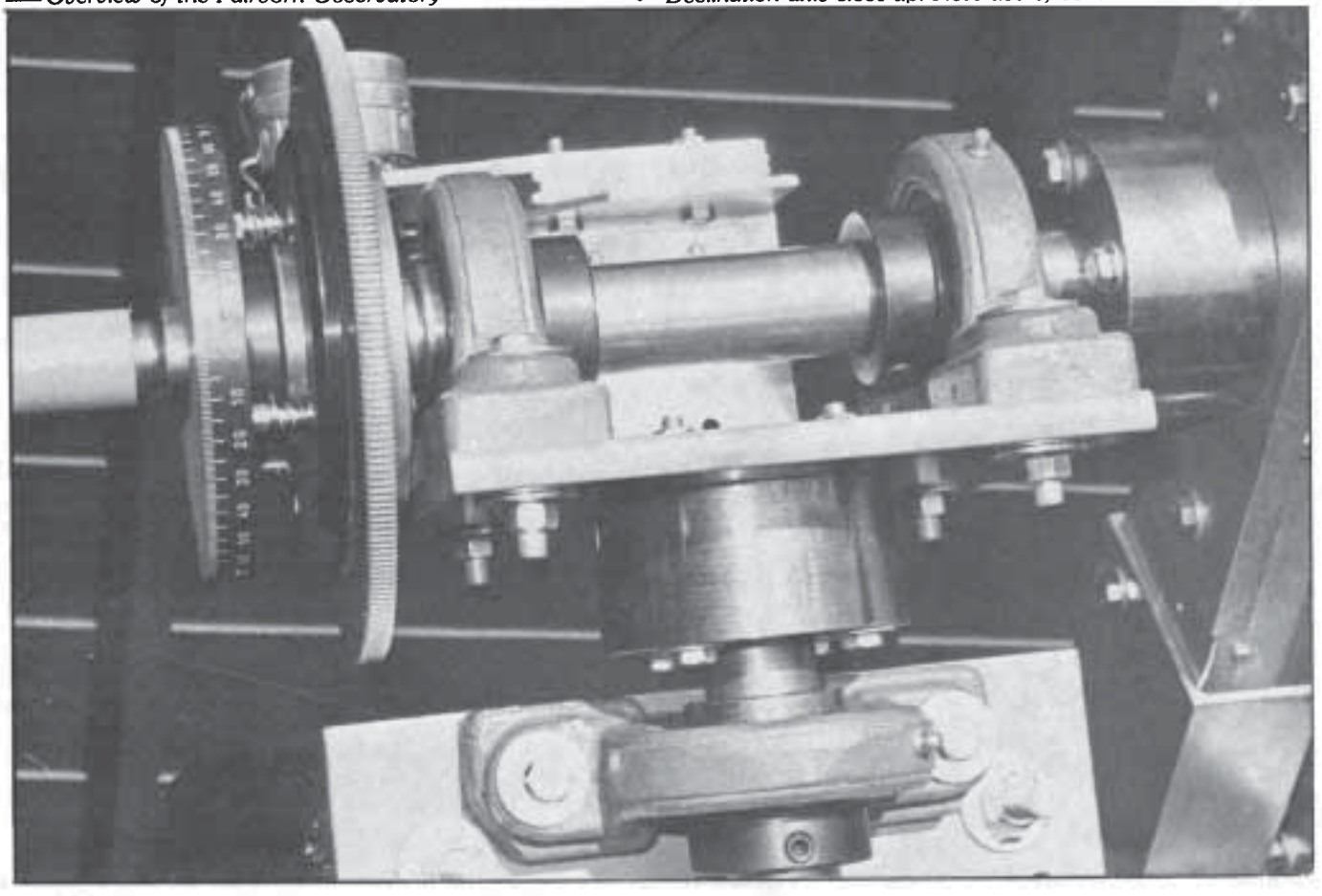
I decided early on not to attempt to grind my own mirrors. I ruled out an aperture less than 8" (insufficient light-gathering power), while one larger than 12½" was prohibitively expensive. I finally decided to start out with an 8", but build the mount, drive, etc. so that a 12½" could be easily accommodated later. This was by far the toughest decision I had to make, but I didn't want to be caught short on funds for instrumentation. (I now wish I had gone with a larger mirror.) Coulter Optical provided the mirrors, and they are of excellent quality.

Although I definitely like the "professional" looks and rigidity of a truss tube, protecting the baffled primary and secondary mirrors when the telescope is not in use can be difficult with this type of tube. The open tube also lets in stray light from the observing floor. For its inherent simplicity, I opted for a fiber glass tube mounted on an aluminum I-beam. Lacking much mechanical ingenuity, I purchased the mirror cells, spider, etc. from the Ken Novak Company. They are all of excellent quality and reasonably priced.

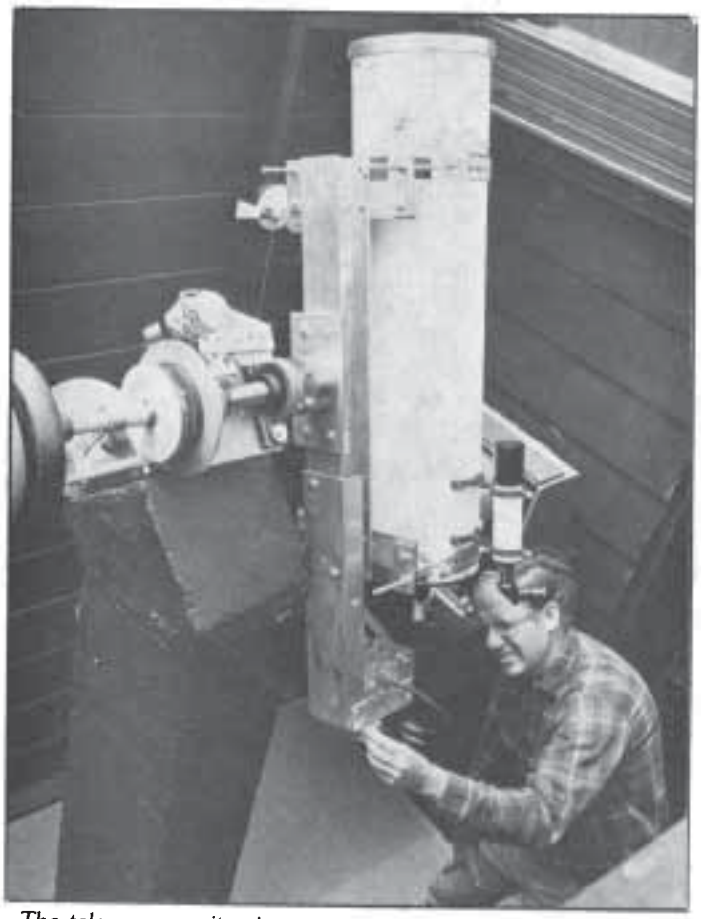
The mount configuration was another tough decision.



▲ *Overview of the Fairborn Observatory*



▼ *Declination axis close-up. Note use of commercial bearings.*



The telescope on its pier.

Making minor adjustments.

Two pier mounts (yoke, etc.) are very rigid and would be my choice if I were to do it again, but I was overly concerned about the height of the north pier. I considered a fork mount's convenience in crossing the zenith without reversal. But it was the German mount I finally selected, primarily for its good rigidity and easily obtained parts. The 1½" steel right ascension and declination shafts, collars, and bearings were provided by Opticraft Machining in nearby Lima, Ohio. Altogether the mount weighs about 200 pounds. The 10" right ascension and 7" declination worm drives and clutches were provided by Thomas Mathis. They are beautiful examples of precision machining and they have performed very well in this exacting application.

Observatory

I decided quite early that it would be necessary to mount the telescope on a permanent pier in some sort of shelter, as having to set up and align a telescope before every observing session would quickly dampen any observational program, especially during Ohio winters! I considered a dome (what amateur astronomer wouldn't love a bright shiny dome?), but finally decided in favor of a roll-off roof. They're cheaper, quick cooling, and not obtrusive (an important security consideration).

To provide protection from the cold Ohio winter winds, the telescope was mounted on a pier 7′ above the floor and the walls extended to 9′. While this blocks vision for the first 20° above the horizon, photometric observations taken this low aren't of much value, but blocking the wind is. A high pier leaves plenty of free working space below the telescope and also keeps it out of the way of the five junior members of the observatory's staff.

The pier is reinforced concrete extending 5′ below the ground and 7′ above the ground. It is 1′ square. The form was carefully aligned on Polaris in azimuth and elevation prior to pouring. The concrete-truck driver said that he had been pouring for many years, but this was his first telescope pier. Four ½" bolts protrude from the pier top to secure the mount. The pier is isolated from the observatory floor.

Photometer

As mentioned previously, I use the standard UBV system as defined by Johnson and Morgan. This essentially specifies the photomultiplier tube and filters. The photomultiplier tube can be either an RCA 931A or 1P21, identical except that the 931A is cheaper but usually has a higher "dark current" than the 1P21 (ref. 4 and 5).

Dark current is the output produced by the photomultiplier when there is no light input, and it is due primarily to thermionic emission (ref. 6). The dark current can be reduced by cooling the photomultiplier with crushed dry ice, a feature I hope to add later.

The general layout of the photometer is shown in the line drawing. Light from the star enters the telescope, comes to a focus, and encounters a diaphragm with a very small hole in it placed in the focal plane of the telescope. The hole is just large enough to let the light from the star (and a bit of surrounding sky) through while blocking most light from the surrounding field. The size of the diaphragm depends on seeing conditions; when seeing is not steady, the hole must be larger to accommodate the jitter in the star's position and will let in additional sky light.

The light, after passing through a filter admitting a selected portion of the spectrum, is then focused by a Fabry lens on the photomultiplier's photocathode. There are separate filters for ultraviolet (U), blue (B), blue-green or visual (V), and "red leak," plus "no filter" and "opaque." The Fabry lens forms an image of the telescope objective on the photocathode, so that movement of the star in the diaphragm doesn't cause the light to move on the photocathode.

When a "flip mirror" is moved into the beam, light is sent

through the relay lenses to an eyepiece with an illuminated reticle. This is a low power microscope focused on the diaphragm in the telescope's focal plane and is used to center the star. Provisions must be made for changing both the diaphragm hole sizes, the filters, and flipping the mirror without perceptably moving the telescope.

The accompanying photographs show the photometer's mechanical and electronic parts. The photomultiplier, which is absent from the pictures because exposure to excessive light could ruin it, requires a regulated and adjustable voltage between about 600 and 1000 volts DC. This is provided by the power supply. The output of the photomultiplier photocathode is around a femtoampere, or 10^{-15} ampere. The tube has internal amplification of a million times resulting in an output from about one nanoamp to a microamp, and this requires amplification by a DC amplifier. The heart of the DC amplifier is a FET input operational amplifier, the small round object in the case. The output of the DC amplifier can drive a meter, a strip chart recorder, or other recording device such as a computer or video monitor.

Stellar magnitudes are determined by comparing the output from the DC amplifier on known and steady "comparison" stars with that from the star being measured. If these stars are at different zenith angles, as is often the case, a correction must be applied to account for the greater atmospheric extinction at lower zenith angles.

Additional information on the schematic diagrams for the high voltage power supply and DC amplifier are available from the author (SASE appreciated). These circuits were designed by Howard Stokes. RCA now makes a transistorized power supply/photomultiplier tube socket/voltage divider in a single unit at a very attractive price (ref. 7), which would greatly simplify the electronic work required to get into photometery.

Supporting Equipment

Supporting equipment can be quite simple, yet good results can still be obtained. A good quality meter (0-1 ma) or digital voltmeter are all that are really required for observing stars, although a strip chart recorder gives a permanent record (some swear by them...others think they're a pain). For occultations, an accurate clock, or preferably a shortwave receiver that can pick up the National Bureau of Standards time signals (WWV), is also required (ref. 8).

In my case, I have a second DC amplifier (Keithly Model 202A), a shortwave receiver, a Monsanto Model 501A strip chart recorder, and a TRS-80 computer and video display.

The computer is used to calculate extinction corrections, heliocentric time, etc., and an interface is being developed for direct recording of the photometer output and control of the telescope pointing. This is particularly useful for observing details during an occultation where a reading every thousandth of a second can be made. I'm also working on a photon counter, to be used instead of the DC amplifier, and a local "clock" (an electronic oscillator) that can be adjusted to match the shortwave signal from the National Bureau of Standards to within a few milli-seconds.

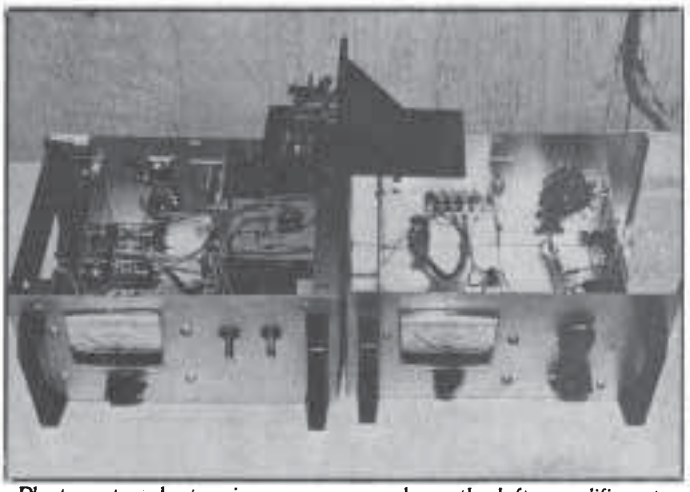
It must be stressed, however, that all this gadgetry is "frosting on the cake"; useful photoelectric observations can be made using only a simple meter as an indicator.

Operation

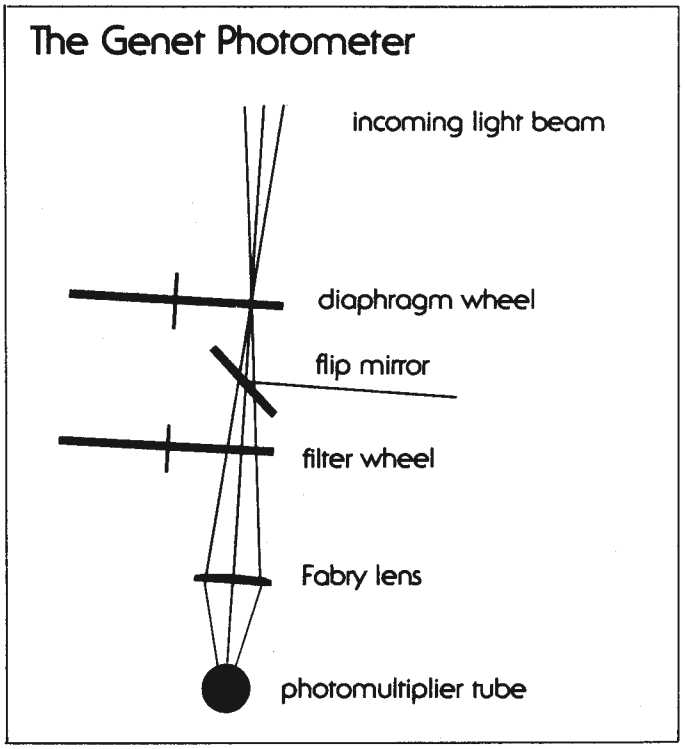
Operation of the observatory is straightforward. The roof is rolled off and while thermal equilibrium is being reached, minor adjustments to the equipment are made. The necessary data are then entered into the computer. Finally, the first star of the evening is located, and work begins.

Helpful Amateurs and Professionals

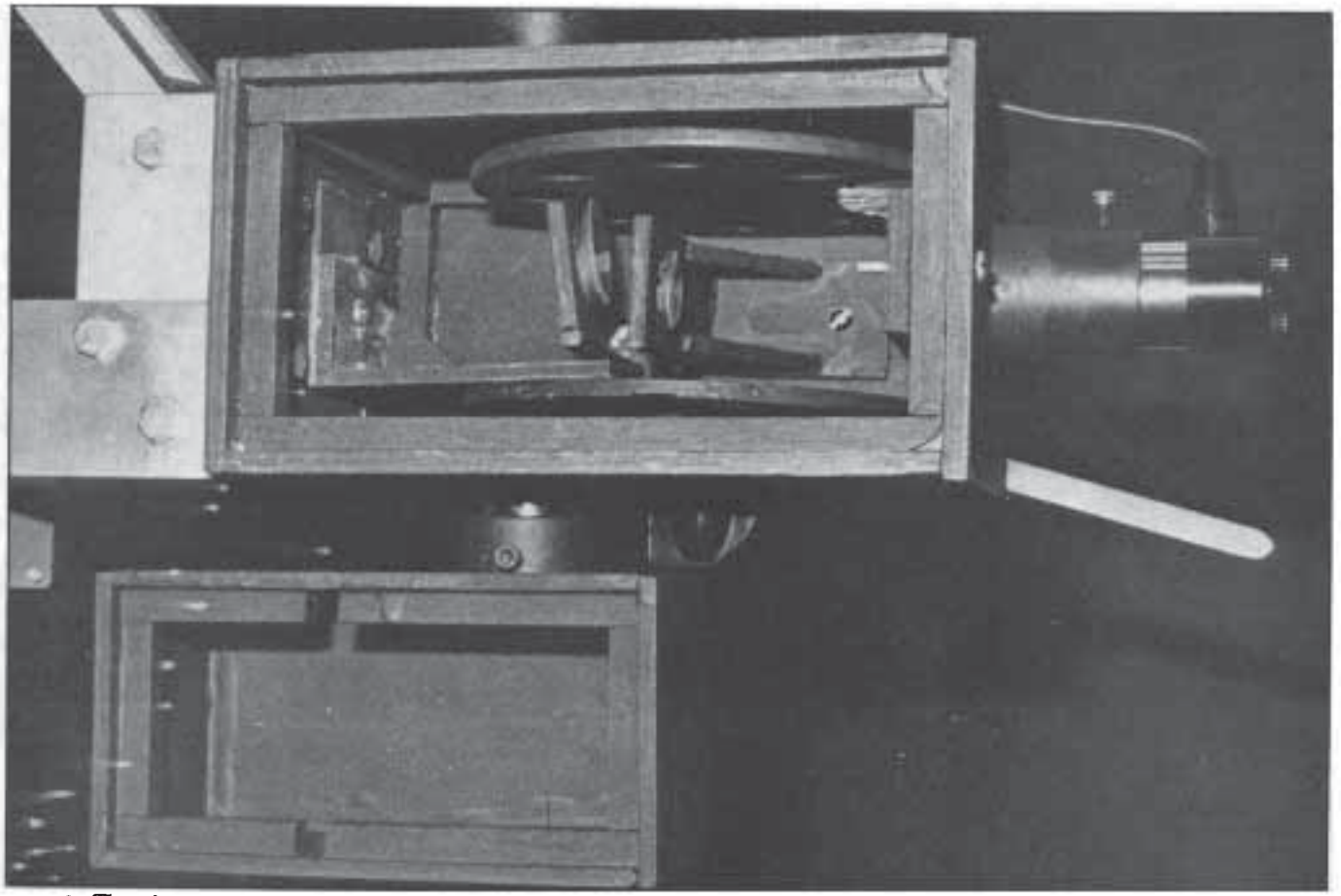
The most pleasing aspect of this project has been the support and encouragement I received from other amateurs and also from professional astronomers. Being a complete novice in the field of photometry, I wrote quite a few rather



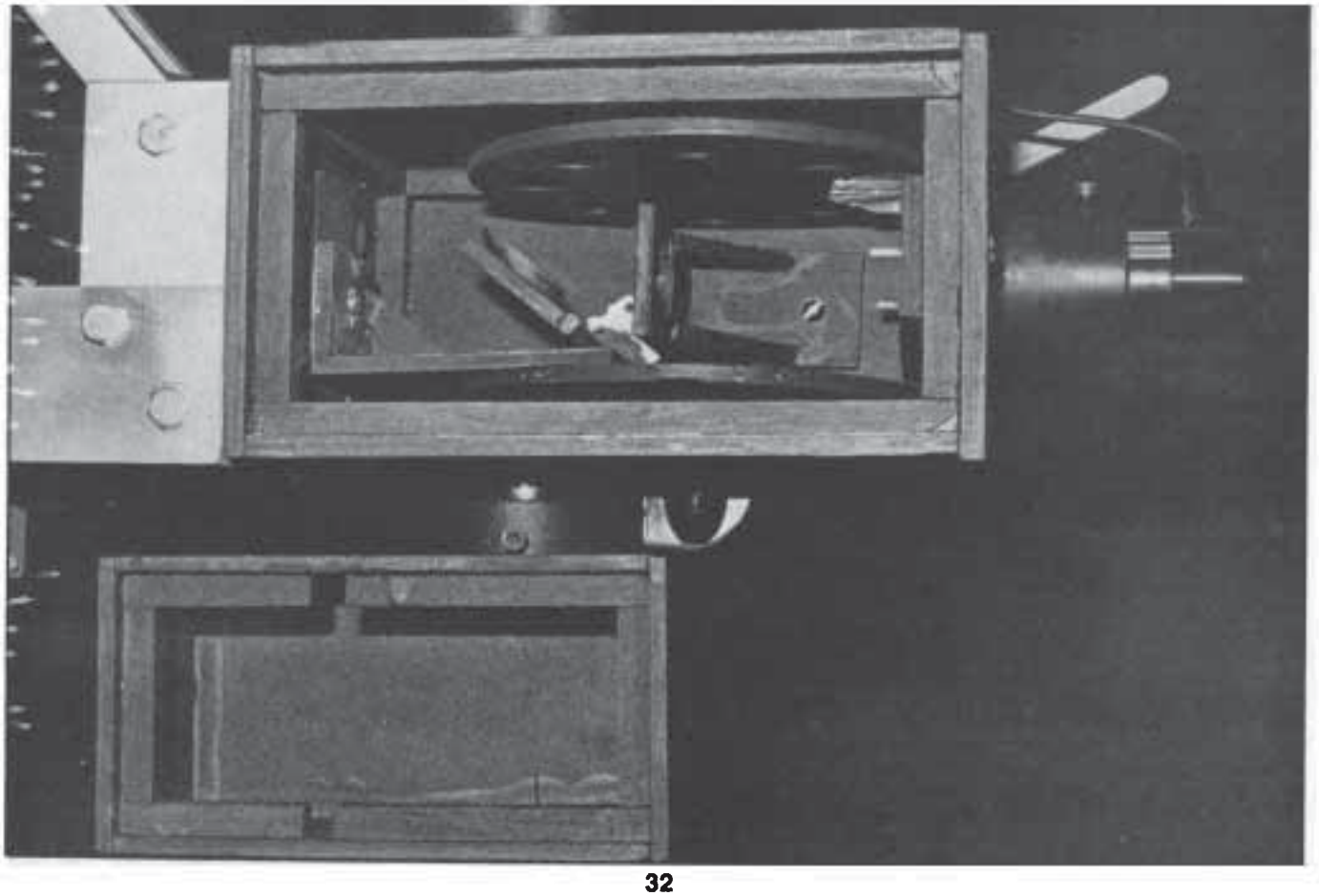
Photometer electronics: power supply on the left, amplifier at right, mica-filled tube base resting across the other two boxes.



Supporting equipment.



▲ *The photometer head "mirror up."*



▼ *The photometer head "mirror down."*

lengthy letters filled with questions, and the replies were all helpful and most were quite detailed. What follows is both an acknowledgement for the help I received and a very brief and incomplete account of those active in this field.

Six amateurs were particularly helpful.

David Skillman has a 12" Cassegrain he has just completed, although he has been observing on a borrowed telescope for a couple of years. He has an interface with a KIM microprocessor.

Howard Louth has a 10" Cassegrain (with a corrector plate of unique design), pulse counter and other digital electronics. He is a very experienced observer. His observatory is described in reference 9, and his photometer will be described in an upcoming issue of *Sky and Telescope*.

Art Stokes is another "old-timer" in photometry. I used his designs for the power supply and DC amplifier (ref. 10). He also kindly provided me with some special low noise cable.

Howard Landis is the chairman of the AAVSO Photoelectric Committee. He has a very nice 8" Newtonian housed under a dome.

Leonard Kalish and Dick Start are two other experienced and helpful amateurs equipped for photoelectric photometry.

Finally, Marvin Baldwin, although he is "strictly a visual observer," suggests what might be observed and uses the data. Marvin is the chairman of the AAVSO Binaries Committee.

The professionals have also been lots of help. Dr. Kenneth Kissile, of the Air Force Avionics Laboratory, has been a constant source of inspiration and a gold mine of astronomical and photometric techniques. Ken has also opened his sizable astronomical reference library to me and provided the Keithly electrometer (long since retired from service at Ohio State University).

Dr. Peter Chen, of the Warner and Swasey Observatory, has been a collaborator in interfacing microprocessors to photometers for high speed occultation observations. He and his charming wife Ann were also the first visitors to the not-yet-completed "Fairborn" observatory.

Major Salvadore Balsamo, of the Air Force Institute of Technology, has been most helpful in working out the details and breadboarding the computer interface.

Dr. David Evans, at the University of Texas, has provided helpful suggestions. He has an excellent two-part paper on the photoelectric observation of occultations in *Sky and Telescope* (ref. 11).

Dr. Robert Millis, at Lowell Observatory, and Dr. J. Elliot at MIT provided helpful information on analog recording for high speed photometry, although I decided to go the direct digital route. Their equipment is described in the *Astronomical Journal* (ref. 12).

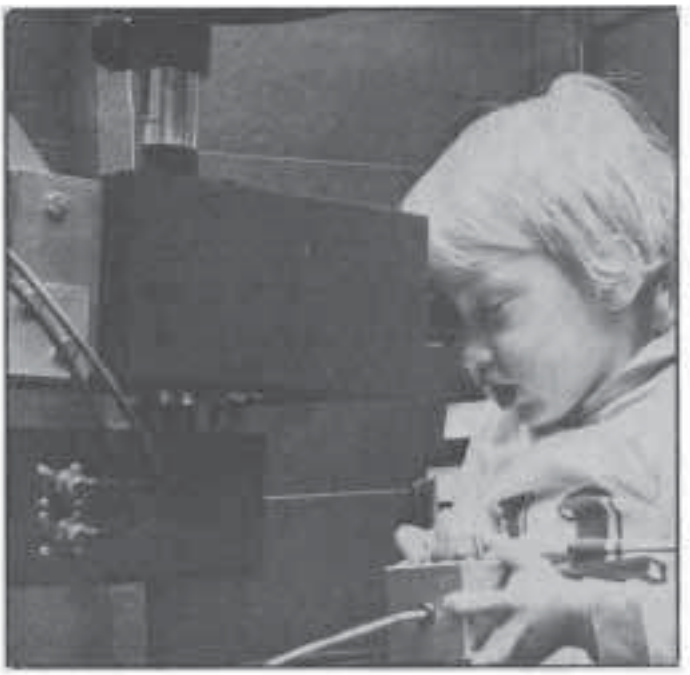
Dr. Carl Lukas and Dr. Thomas Van Flandern, both of the U.S. Naval Observatory, have been helpful in regards to occultations and timing. Dr. Van Flandern's paper on occultation timing is excellent (ref. 13). He also acts as the focal point for data receipt and analysis on occultations, together with David Dunham of the International Occultation Timing Association (IOTA).

Last but certainly not least, Dr. Douglas Hall and Gregory Henry, both at Dyer Observatory, have a very active program that utilizes amateur photometric observations in professional astronomical research of current interest. For instance, they have requested and utilized photometric observations from amateurs on the peculiar RS Canum Venaticorum (RS CVn) binaries. This research is described in reference 14 and in a series of articles in the *Astronomical Journal* (ref. 15). Several of the amateurs mentioned earlier were co-authors of these papers.

Conclusions

While the construction and equipping of an amateur observatory for photoelectric photometry is not a project to be tackled lightly, it is within the grasp of any serious, dedicated amateur. The observational results can be very precise, within 0.01 magnitude with respect to comparison stars, and are sought after and utilized by professional astronomers such as Dr. Hall (variables) and Dr. Van Flandern (occultations).

I would be glad to answer any questions that I can or provide references to some of the more experienced amateurs or professionals.



Russel, Jr. centers a star.

Russ Genet
Fairborn Observatory
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Fairborn, OH 45324

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Mockingbird Hill Observatory

by Earle F. Dodds

When my stargazing project started here on Mockingbird Hill, I made a commitment that I wouldn't place an "unsightly shack" in the backyard. I had a portable telescope, as do many amateurs, which "lived" (most of the time) indoors. It "worked" (very occasionally) out in the open backyard. There I had a stationary pier, carefully positioned to put the majority of several nearby mercury vapor street lights behind houses, trees, and basketball backboards.

The scope was truly portable: It "took-down" at the polar axis and the pier head and part of the polar axis were permanently attached to the top of the pier. One thing I didn't have to bother about was re-aligning the axis to the pole every time I set up.

However, it didn't take very long for the setting up and taking down of the telescope (not to mention the nuisance of having it in my shop when I wanted to work) to become an unacceptable burden. I decided to move the telescope permanently out onto the pier and to build a shelter around it. This brought with it a whole series of other decisions.

The first was how big to make the telescope room. I wanted to keep it as small as possible. My telescope is a 6" f/8 Newtonian reflector — a common enough size — but it is also a stationary eyepiece type. The tube is attached to the declination axis much farther away from the mirror end than is the case for a conventional Newtonian. This requires a somewhat higher pier and also more swing room than do most 6" f/8 reflectors. By swinging the scope around in several critical positions and taking measurements, I found that I could get by with an eight foot square enclosure if I centered it not on the pier, but a foot north of it. I'm inclined to believe that an eight foot square area would be adequate for most 6" f/8 reflectors, but if you're concerned with other sizes and ratios, you should do some swinging and measuring before you decide on the dimensions of the telescope room.

My second decision was what kind of construction and what kind of material to use. I decided to use pole construction with "Stockade Cedar" fencing for the walls. In pole construction there is no foundation, no floor, no framing, nothing but the posts upon which the wall material is hung. For the posts I used pressure treated 4 x 4s — dressed they measure only 3½ x 3½ — eight feet long. Stockade Cedar fencing comes in prefabricated panels eight feet long and in four, five, and six foot heights. It consists of closely fitted pickets of western white cedar, machine-nailed to three horizontal stringers. Made for fencing, these panels are nailed directly to the fenceposts.

Since I do most of my observing alone, the roof had to be a roll-off job. I couldn't go with anything that lifted off or was pivoted some way so it could be swung off. Even as a roll-off lid, it had to be one-man light. I'd had experience with one other roll-off roof — it was built so strong and heavy it took a half dozen men and a small boy to roll it off and back on without everybody getting hernias and heart attacks. I agree with what John Simpson says (on page 24 of TM3) about the general unsightliness of the outside support frame for roll-off observatories, but I think I licked that problem and honored my "no ugly shanty in the backyard" commitment.

My last major decision was what height fencing to use. This depends on what kind of horizon you have; since from my backyard the true horizon is obscured all the way around by houses and trees, I chose panels six feet high. This cuts off a lot of extraneous light and also blocks the wind from the northwest (I surely do appreciate this during the winter observing season). The six foot height also gives me adequate headroom to work around inside the observatory while the roof is in place. You'll have to decide what height is best for your own specific location and condition. If you have a good horizon view, don't sacrifice it for headroom: when the roof is off, you have infinite headroom.

One of the main reasons why amateur carpenters come out with some sorry looking jobs is that they don't observe the rule of "keep everything square, level, and plumb," but to do this you've got to start out square. The staking-out diagram I used is shown here. If these dimensions fit your needs, fine and dandy, but if they don't, modify them so that they do. I assure you that an accurate layout job before you dig the first post hole will pay dividends later on. If you have access to and know how to use a builder's combination transit-level instrument, you'll have no trouble following the diagram to lay out the post holes. If not, the following detailed instructions are for those who have to do the job with a tape and a chalk-line.

Provide yourself with about two dozen good stakes, made from 2 x 2 material, each about 18" long. Determine where Point A, the southeast corner of the project, must be and drive a stake there. (The location of A will depend upon the location of your pier and how much swing room you need in every direction, but this decision has already been discussed.) Drive a 1" finishing nail (not a tack) about half way into the top of the stake. Leave the nail sticking up so you can hook the tape and chalk-line on it later. Next, with steel tape, measure off 18 feet from A in a northerly direction and set a stake at point F. Your observatory does not necessarily have to run exactly north and south, but it ought to be approximately so. Measure again with the tape and set a nail in the F stake exactly 18 feet from the nail in stake A. Line A-F is your base line, and I cannot stress too strongly the importance of setting these two starting points as accurately as possible.

These two corner stakes will, as will all the other ones, be dug out when you dig the holes for the posts, so you must "reference" them in. You do this by setting stakes A-1 and F-1. The distance of these reference stakes from the corner stakes is not critical, but they should be set back far enough that they'll be out of the way and not disturbed by your construction activities. They must be in line, however. Hook the loop in the end of a chalk-line over the nail in F. (Instead of using a regular cord chalk-line, I used a piece of 20# test mono-filament fishing line. You can stretch it tighter, it doesn't sag so much, and since it is much finer than cord, you can do more accurate work.) Stretch it on past A a few feet and line up the line so it just "kisses" the nail in A. Drive stake A-1. Again, using the chalk-line, set a nail in it in line with A-F. Now, go to F and set reference stake F-1 exactly the same way you did A-1.

The next step is to set stake C exactly 8 feet from A and at a true right angle from line A-1 — F-1. Getting line AC dead square with AF separates the men from the boys. This is where most amateur (and some professional) carpenters get a job messed up; they just don't take

the time to make things square to start with. With a transit instrument that can turn a right angle, the task is easy, but you can be just as accurate with a tape and chalk-line. All you have to know is the Pythagorean proposition and calculate the diagonal of the rectangle.

I've done it for this layout diagram — if you modify the dimensions you'll have to calculate it yourself. To the nearest 1/16", the diagonal FC is 19' 8⅜". If you have two tapes,hook the end of one onto Nail A, the other to nail F and maneuver yourself around until one tape reads exactly 8 feet when the other reads 19' 8⅜". If you have only one tape, you've got to alternately measure the correct distances from A and from F. Set stake C and put a nail in it at exactly the correct distances from A and F.

Next you set stake H the same way you did stake C, and to be sure you did everything right, measure the distance C-H. It had better read 18' 0", bang on, or you must go back and find where you made a boo-boo and correct it. After you have C and H set, you reference them in with C-1 and H-1 the same way that you set stakes A-1 and F-1.

Now that you have the corners A, C, F, and H established and referenced in north and south, you reference them in east and west, setting stakes A-2, F-2, C-2 and H-2 by stretching the chalk-line through A and C and also through F and H. After you have the four corners established and fully referenced in, you can set and reference in points B, E, D, and G, using the same techniques that you did for the corner posts.

Note that points A through H do not represent the centers of the posts but rather one of the corners thereof. When you dig the post holes you will have to offset them from the control points by about 2½" in a diagonal direction. If you use six-foot fencing, the holes will be about two feet deep. Since the tops of all the posts must come out at the same level, the bottoms of all the post holes must likewise be at the same level. Again, if you have access to a builder's level instrument, this task is easy, but if not, you can use what is known as a "string" level. A string level snaps onto a chalk-line and is very sensitive. You can do accurate work with it if you keep the string tight and make sure the level is exactly — within a quarter of an inch — at the center of the span of the string. Set a "bench-mark" stake approximately in the center of the project and drive a "hook-onto" nail in it.

The second drawing shows how the level of the bottom of a hole, with reference to the top of the bench-mark stake, is determined. This will probably be a two-person job — one to stretch the line and measure the distance from the hole bottom to the string, the other to watch the level bubble and tell the measurer whether to raise or lower that end of the string.

If you try to set these posts and backfill them into final position one at a time, you'll probably have an exasperating time trying to get them to line up exactly. Sooner or later you're going to have to cut a notch in the upper ends of those posts to accommodate the stringer which will carry the roof, and you might just as well do it before you try to set any posts.

If you refer to the framing diagram for the roof trusses, you'll see how this stringer frames into the tops of the posts. The web member of this stringer is a 2 x 6 on edge, and it should be 20 feet long so you will have adequate room to run the roof entirely off the telescope room. Lay out the positions of the posts on these 2 x 6s and fasten the notched tops of the posts to the 2 x 6 with a single ¼" carriage bolt. Don't tighten the bolts until later — leave the posts free to pivot on the bolts. Next, "borrow" the 20 foot 2 x 4s you will use for the flange member of the stringer, lay out on them the positions of the posts, and tack-nail them to the posts about three feet above the bottom ends of the posts. Square up the posts with these longitudinal members and lightly tack-nail the necessary cross bracing to maintain the squareness. Don't use a carpenter's square to do this squaring up; rather use the 3-4-5 principle as shown in the erection diagram.

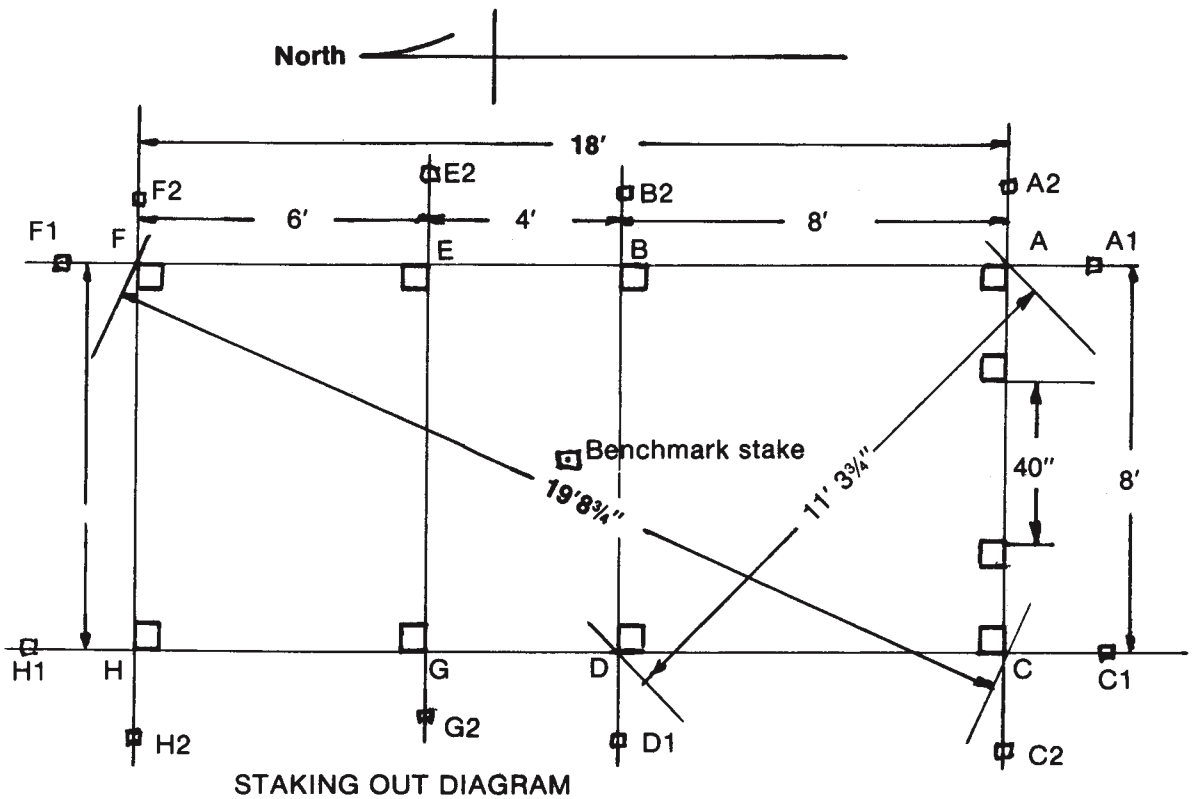
You can drop these pre-assembled sets of posts into their respective holes as units. You can hold them upright with a brace on each side of the building. After these sets of posts are resting in the holes, you can stretch the chalk-lines between the respective reference stakes and nudge the units around until they line up with their respective lines. Keep both units plumb, using a carpenter's level at least 24" long. Make sure, even if you have to do some temporary cross bracing from one side to the other, that these side units are exactly parallel and that the posts are exactly 96" apart, outside edge to outside edge. I found it convenient to tack-nail one end of the cross bracing and hold the other end temporarily in position with a C clamp; then when you achieve satisfactory alignment, you can replace the C clamp with nails. While you are about this, do some checking with the string level to be sure that the stringers are not only level lengthwise but that they are at the same elevation crosswise.

All this squaring, leveling, and plumbing may seem like a lot of "Who shot John?", but if you want the roof to roll off and back on smoothly, without pinching or binding, you'd better do it before you backfill the posts into final position. For the backfilling I recommend using inundated sand (see the article on Permanent Piers, page 26 of TM2). There is no need to re-plow that field in this article. The problem is the same.

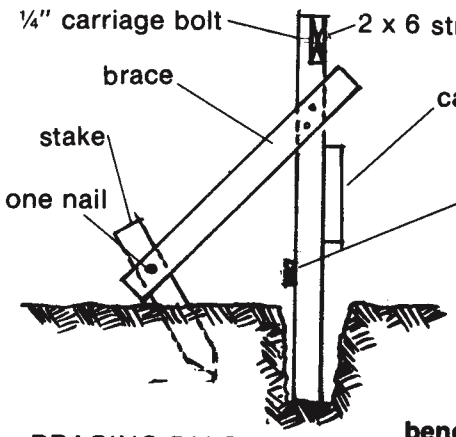
After you have the posts backfilled into place, you should then put on the final cross bracing of the framework north of the telescope room. Because I intend ultimately to enclose this space in my observatory, I put the cross bracing on the insides of the posts and left out the bracing in panel B-E because that will be the doorway to the enclosed space.

The Stockade Cedar panels should now be nailed to the posts surrounding the telescope room using 30-penny galvanized nails. Since the panel stringers will all be at about the same level, be careful not to center the nails on the stringers or you will have them colliding inside the posts. In the south wall of the telescope room you will need a gateway. Be sure to get a few extra pickets — you'll need at least four of them to finish off the corners.

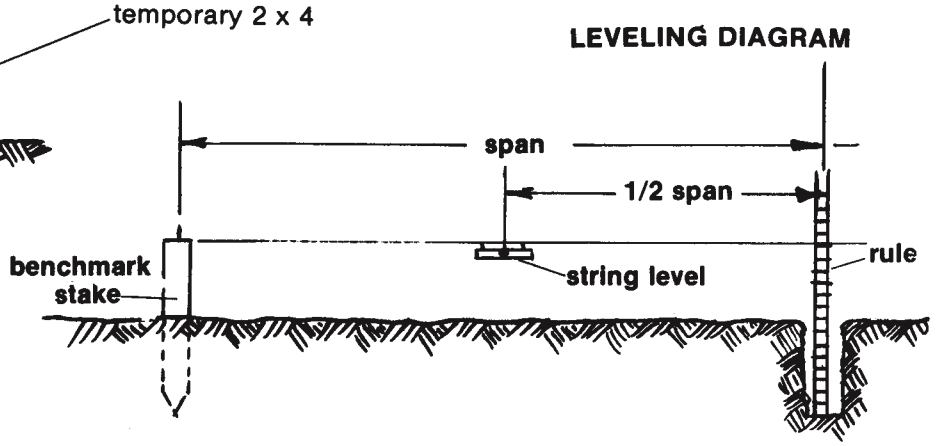
You can fasten the 2 x 6 roof-bearing stringers to the top ends of the posts with a couple of 16-penny nails, beefing up the connection provided by the quarter inch carriage bolts. You should also take off those 20-foot 2 x 4s you used to hold the bottom ends of the posts temporarily in line and nail them flatwise to the top edge of the 2 x 6 web members of the roof-carrying stringers. I used 16-penny coated nails

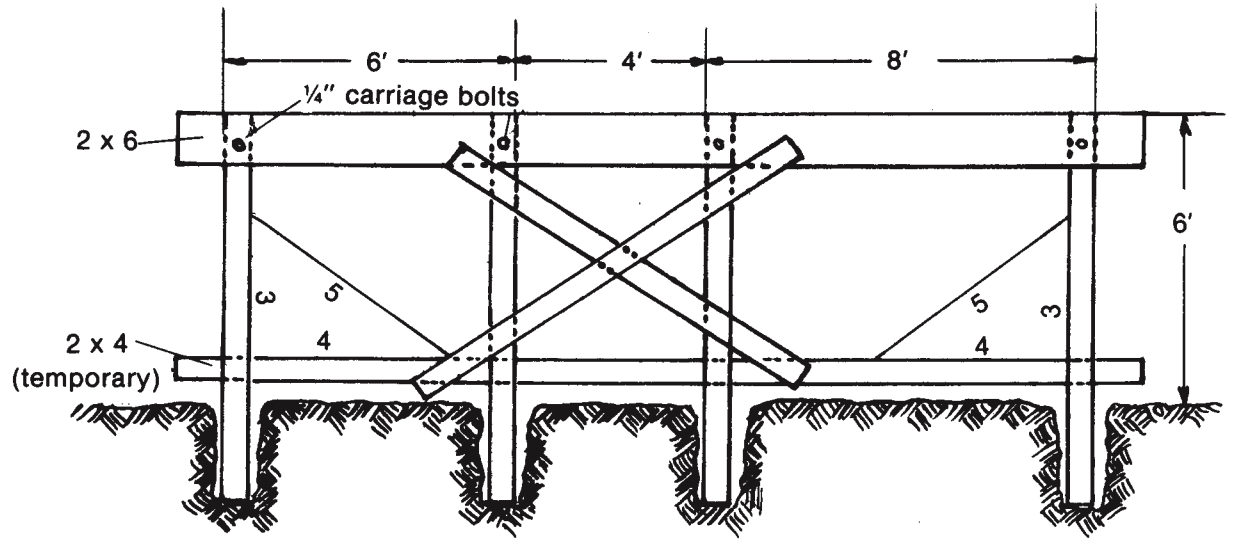


STAKING OUT DIAGRAM



BRACING DIAGRAM





ERECTION DIAGRAM

Mockingbird

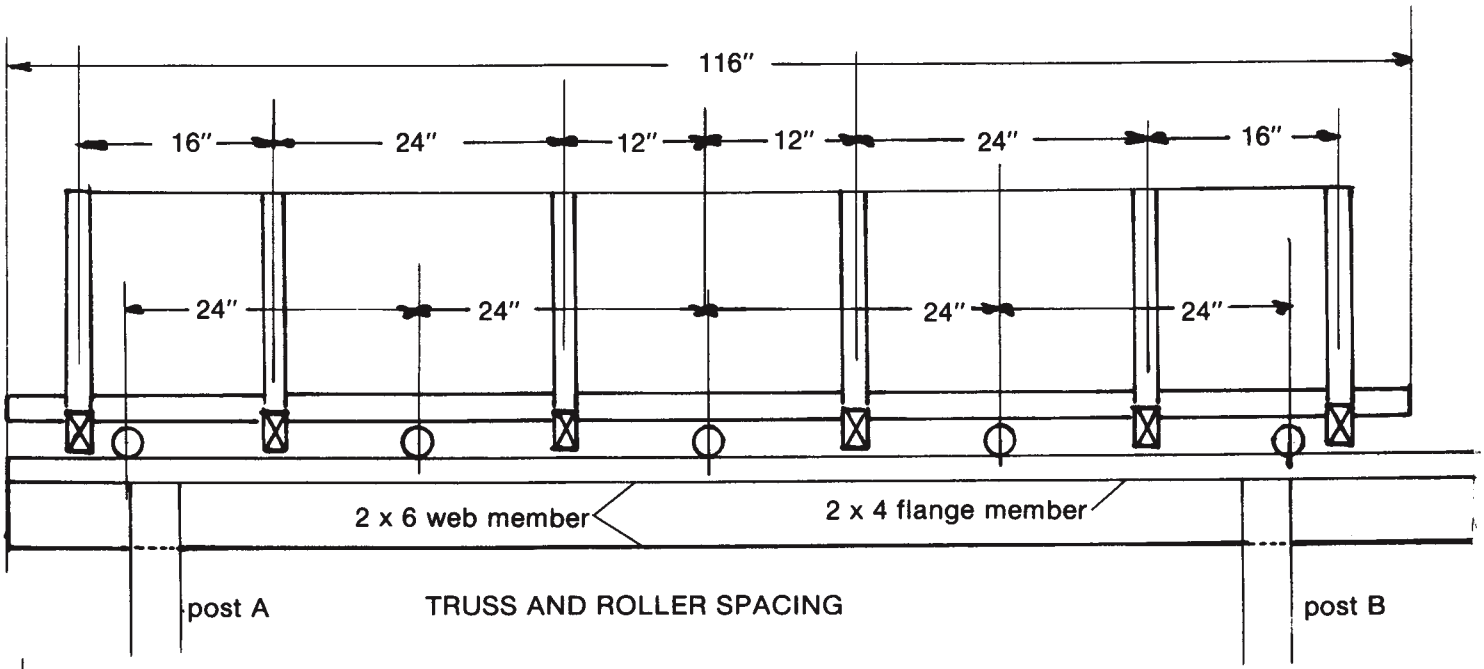
spaced six inches apart to fasten the 2 x 4 flanges to the 2 x 6 webs. Two strips of ¾ x 1 material, spaced an inch and a quarter apart, provide guide strips for the rollers. This about completes the substructure of the observatory.

Next, you'll frame the roof. You probably could call the two sloping members "rafters" and the horizontal one a "ceiling joist," but they actually are the upper and lower chord members of a kingpost truss. The dimensions have been chosen so two rafters and the kingpost can be gotten out of a ten-foot 2 x 4. You may consider dadoing the nailing strips into the rafters an unwarranted refinement, but it sure does stiffen up the entire roof, and it makes nailing on the galvanized roofing much easier.

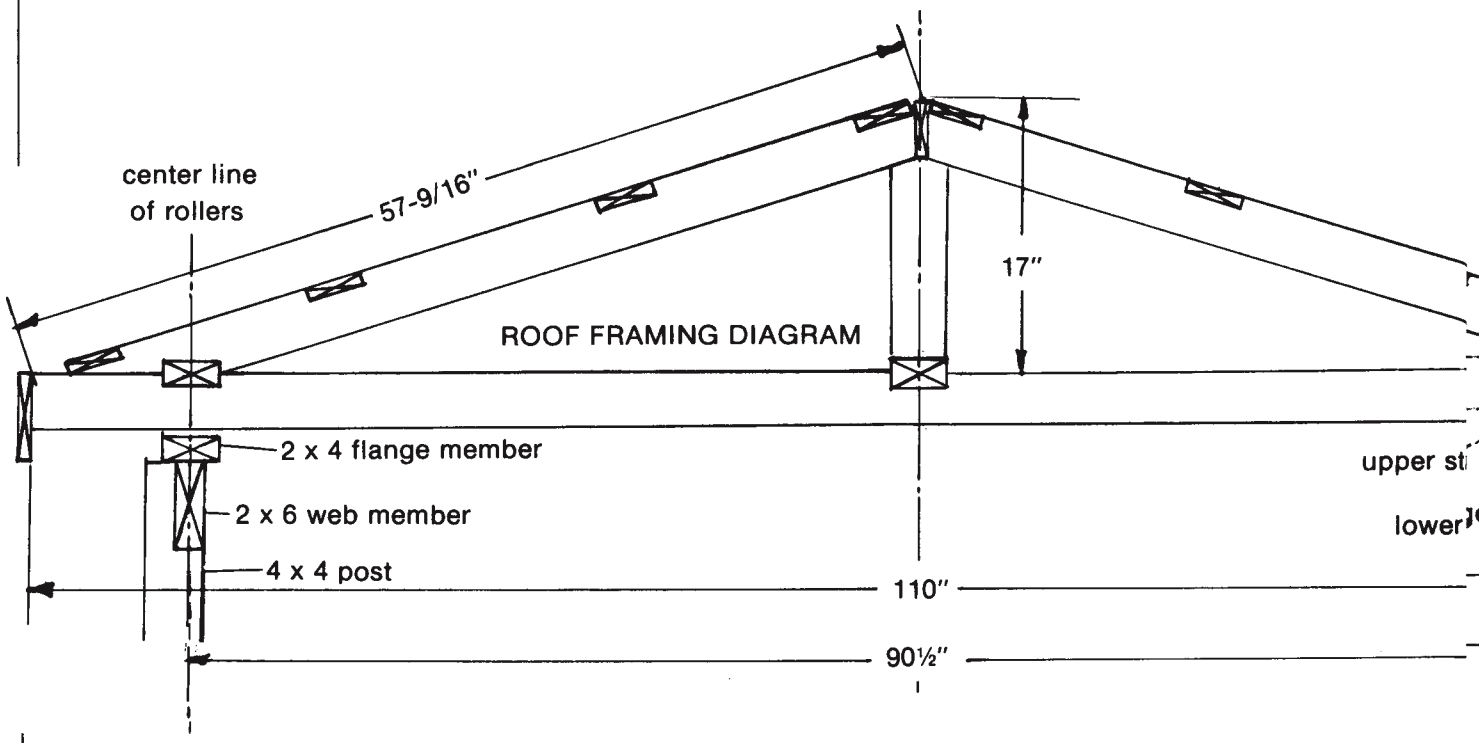
The upper stringers — the ones to which the rollers are fastened — are dadoed into both the upper chords and lower chords of the trusses. This too may seem a refinement, but it makes the construction very strong and rigid without adding any extra weight. The cut into the lower chord is easy, but the one into the upper chord is a little tricky. I did most of this roof framing on a radial arm saw. After making the first truss and getting it fitted together properly, I took it apart and used it as a pattern to make the other five trusses. You can fasten these rafter blanks together face-to-face three at a time and hold them with 6" clamps and cut these dadoes pretty quickly.

I was at first inclined to preassemble these trusses on the ground and try to string them onto the longitudinal stringers like beads. This might work if you had straight and true lumber, but it's easier all around to fasten the rollers to the upper stringers, then set the stringers in place and finally to assemble the trusses around the stringers. You may at first question the need for the longitudinal 2 x 4 at the bottom of the kingposts, but believe me, it distributes the roll-off, roll-on push to all the trusses as a unit. I didn't put one in when I framed up my roof and much of my push-off effort was going into flexing the bottom chord of the truss. I had to go back and put one in on top of the bottom chord members and alongside the kingposts, which made it off center, as you can see in the photograph.

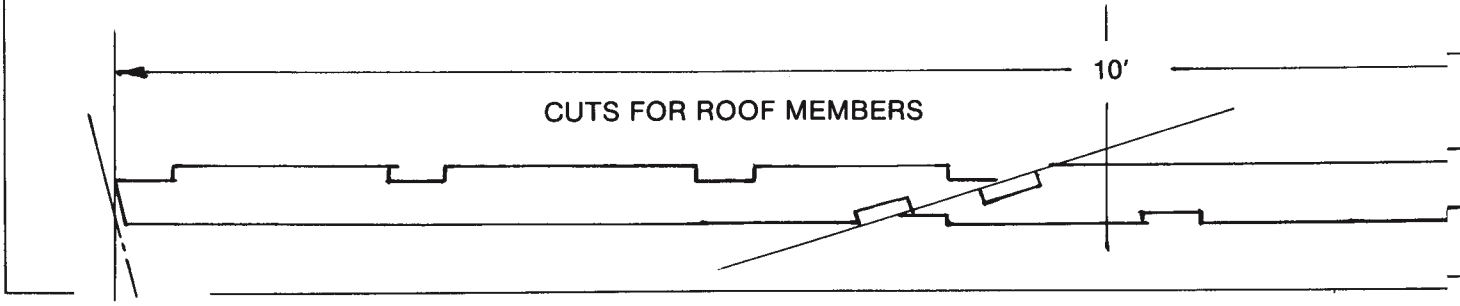
I used 1 x 4 stripping material and ordinary corrugated galvanized roofing, nailed directly to the rafters and stripping without any decking at all. The roof is strong and rigid but relatively light. I have no trouble rolling it off and back by myself.



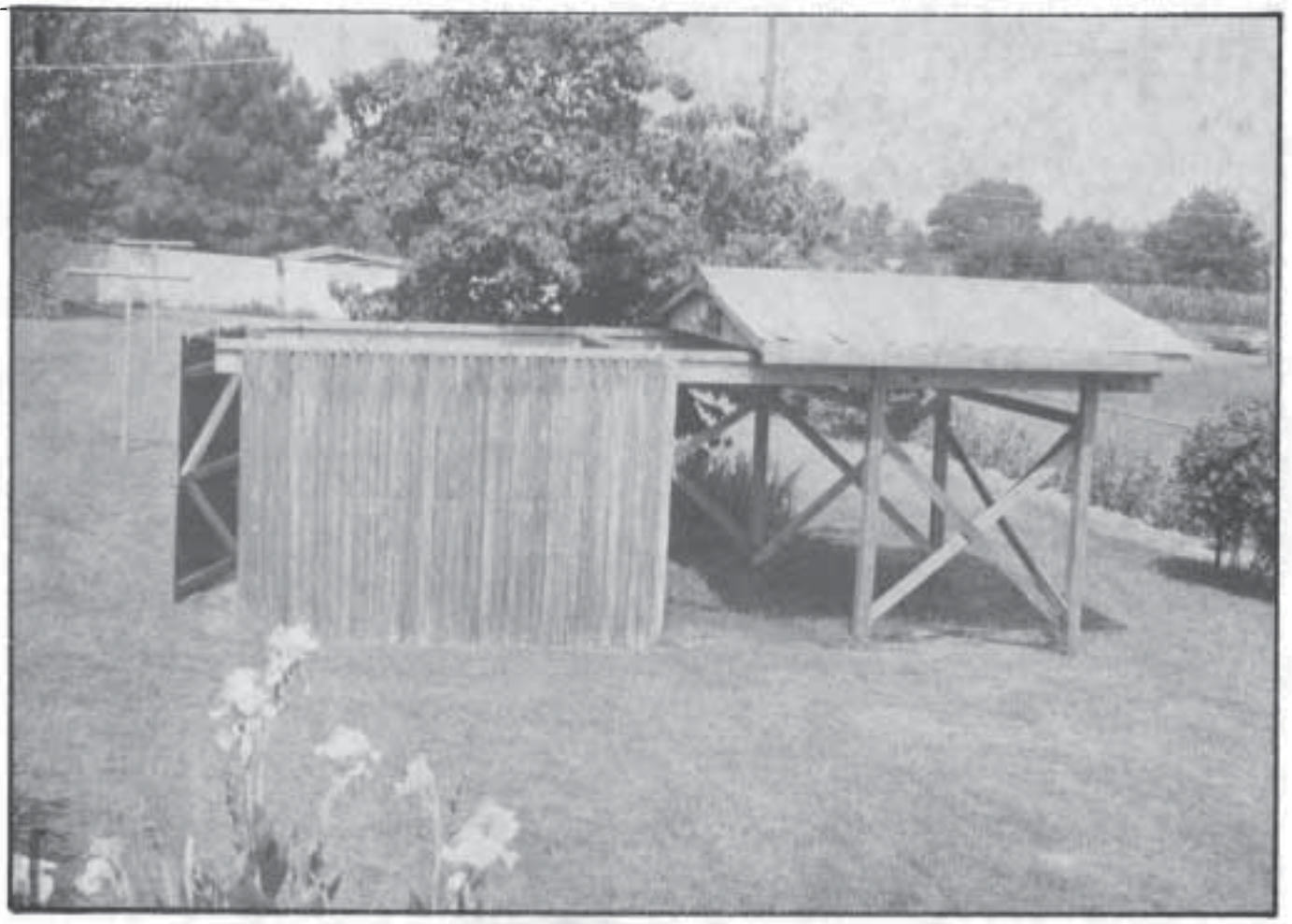
TRUSS AND ROLLER SPACING



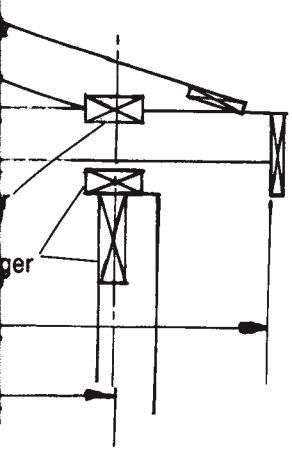
ROOF FRAMING DIAGRAM

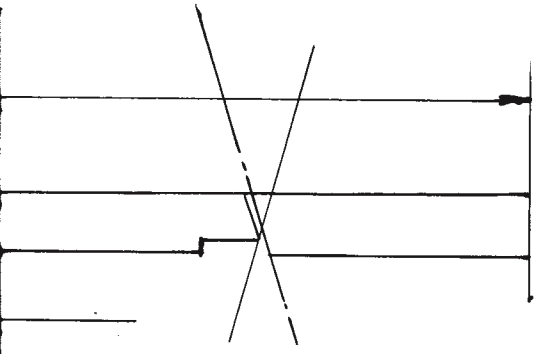


CUTS FOR ROOF MEMBERS



Mockingbird





Neither of the construction drawings indicates anything about the rollers except their location. I used what are called industrial non-swiveling casters: the hard rubber rollers are an inch wide and 2½" in diameter. The axles are 5/16" diameter. These are not ball or roller bearings; they're nothing but the sleeve-type bushing which turns on the axle. Be careful that the side plates of these casters clear the guide strips for the rollers or you may have to do some beveling of the inside edges of these strips to provide the necessary clearance.

You will find it advisable to line the inside of the telescope room with some kind of dead black material. That Stockade Cedar fencing is only nominally tight, and you will have all kinds of stray light as well as cold winds intruding into your observing space. I first tried ordinary tar paper, but that stuff shrinks badly, so much so that after a short while you will not only have a shoddy looking job, but also a whole array of small holes rather than cracks for the wind and stray light to come through.

I also tried black heavy-gauge sheet plastic. This does not shrink, but it is somewhat glossy, and it feels awfully cold when you brush up against it on a cold night. The material I have found best is black-finished insulating board used as storm sheeting in house construction. It's a little more trouble to cut and fit this stuff, but it stays put and it is a welcome barrier to the wind during the winter.

You'll also have to provide some way to fasten the roof to the telescope room lest it blow off during a windstorm. I have simply fastened the two longitudinal 2 x 4s on each side together with six sets of hasps and staples for this, but you can use hook-and-eye latches if you can find some that are long enough.

The observatory is aptly named. If you'll look at the photographs carefully, you'll see a small grapevine just north of the project. A pair of mockingbirds nested in there this spring — the brood came out of the nest a couple of weeks ago, and between the adult birds and the kids we're practically covered up with mockingbirds!

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An Observatory for Deep-Sky Astrophotography

by Thomas L. Dessert

Ever since I became aware of the immense distances, awesome sizes, and peculiar shapes of galaxies, I've felt a compulsion to record them. But recording these images — which have taken from 2 to 200 million years to reach us — was to be a formidable challenge.

The equipment I originally purchased, a 10" f/6 reflector and a 4" f/10 refractor, has had to be modified extensively. As I made each change, I gave careful consideration to each modification to insure its workability and freedom from error.

The first change I made was to the focuser assembly. Most astrophotographers mount their camera to the drawtube of their standard 1¼" or 2" focusers. However because of interference from the drawtube, vignetting of the image can't be avoided, and you still must move the primary mirror forward several inches to bring the focus to the film plane. This compounds the vignetting problem unless the diagonal mirror is replaced with a larger one which in turn causes loss of contrast and larger diffraction rings. And vignetting by the drawtube still occurs.

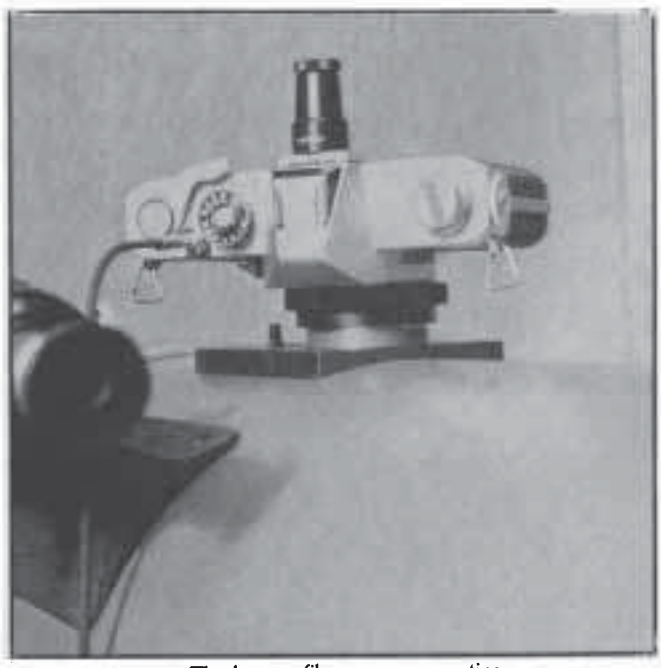
Luckily, there is a much simpler and cheaper solution. The focuser is generally composed of two components, the base and stem casting, in addition to the drawtube. After discussing the problem with fellow members of my astronomy club instrument section, we separated the base from the stem. The base section was machined out to a 2" opening and fine threaded internally. The focuser stem was fitted with a threaded bushing so that it could be screwed back into the base for use during visual observation.

We modified a T-mount camera adaptor removing the threaded bushing insert and replacing it with a ¾" length of aluminum tubing. The tubing was fine threaded inside and out and painted black. The camera could now be coupled directly to the focuser base and focused by threading in or out. With the camera within ¼" of the base, I was able to move the primary mirror back almost ½" and have a completely unvignetted field of 50' x 75' of arc.

Accurate focusing is insured by using a 2.5x viewfinder magnifier to focus a star on the ground glass viewing screen.

My second modification was to install a useful guidescope. I wanted a guidescope that met the following specifications: First, it should work at a minimum magnification of 10 times the focal length of the photographing telescope. Second, it should be able to produce guidable images of stars as faint as magnitude 7. Third, it should be able to be offset 2.5° from the photographic subject and be securely locked in place. Fourth, it must be rigidly attached to the photographing telescope. Last, it should be capable of being used as a photographic instrument.

My first objective was reached by building an eyepiece magnifier equal to a 100x microscope. To do this, I installed a 25x microscope objective lens into a standard eyepiece extension tube. This was fitted to one end of a star diagonal with an illuminated crossline eyepiece attached. This arrangement achieves several desirable objectives at once. Using a 12.5 mm eyepiece which has good eye relief reduces eye fatigue. The magnifier is compact and does not sag or "unload" as you guide. My system produces about 1000x when used with my 42" focal length refractor. Changes in micro-objective magnification and/or projection distance will yield the proper magnification for other focal lengths.

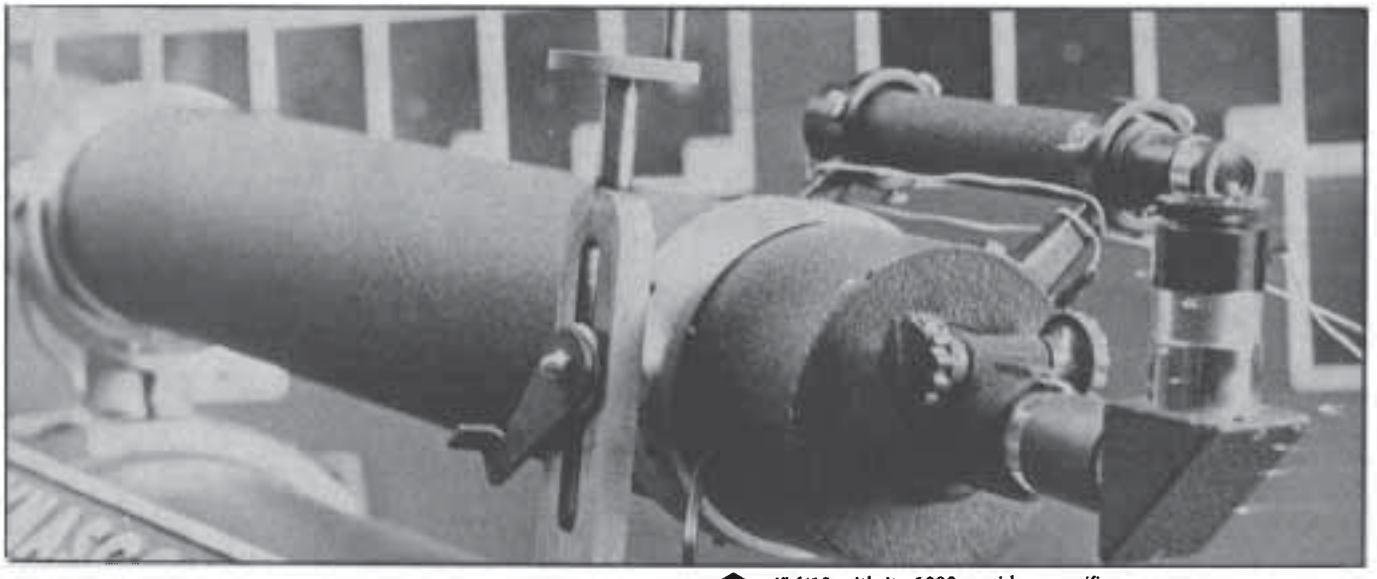


The low-profile camera mounting

To meet my second objective and determine the size of the guider's objective lens, I experimented with aperture stops on the 10" reflector while observing at 1000x. The star images became poor when it was stopped down to less than 4", but cost was a factor in not choosing a lens larger than 4". I determined the focal length of the guider (f/10 in this case) on the basis of the image scale I would require in photographing the larger open clusters — my final objective. The Jaegers 110 mm f/10 covers an 83' x 125' of arc field on 35 mm film.

My third and fourth objectives were reached with the help of my friends in the Buffalo Astronomical Association Instrument Section. I had initially used a pair of 5" guider support rings. These proved to be extremely awkward and troublesome to use for offset guiding, and they were prone to flexure. After much thought and discussion, we produced a pattern and cast it at a local foundry. We then machined it and fitted it to the main telescope tube, also adding stiffeners to the tube itself for added rigidity. I now have a precision off-axis guider mount that is controllable at high magnifications and also free from flexure.

Since I also wanted to use the guidescope as a "photoscope," it was necessary to make the focuser compatible with the camera adaptor. As on the main telescope, the focuser stem was cut free from the base casting. The base plate was then bored out and threaded to accept the previously modified camera T-mount adaptor. The stem and drawtube assembly were fitted with a bushing and threaded to fit



4" f/10 with its 1000x guide magnifier

the base. Care was taken when building the refractor to keep the distance between the camera and base plate as short as possible, about ⅜" in this case. When we designed the baffles for the tube, we took care that there was no vignetting at the film plane. Pictures taken with the refractor are spectacular in contrast and definition.

When I'm photographing with the "guidescope," I guide with the "photoscope." Using the guiding magnifier at approximately 1500x, I have a guiding advantage of about 30:1. With that kind of guiding advantage, I can correct an error almost before it can register on the film. I also use a 200 mm f/3.4 telephoto lens for "wide" field objects such as the North America Nebula, Rosette Nebula, etc. With a red Wratten #29 or #92, I can run filter exposures up to 60 minutes with breathtaking results. When using any telephoto, however, be sure to provide support for the lens barrel as well as the camera body, or flexure will cause unwanted star trails.

While guiding can be done by hand with manual controls, push-button "hands-off" controls are better. I use a stable variable-frequency right ascension motor drive and a variable reversible direct current supply for the declination motor drive. The R.A. slow-motion rates are kept within 5% of sidereal rate, and the Dec. slow-motion rates are geared to about 1 second of arc/sec of time. The DC declination motor drive is also the preferred method for declination control when using dual axis automatic star trackers.

These refinements created a new problem — that of weight. The original commercial mounting was never very steady holding just the 10" reflector, let alone the 4" refractor, guider mount, tracking equipment, camera, and 15 extra pounds of counterweights. After more discussion and advice from the instrument section, a new equatorial mounting was designed and constructed capable of supporting twice my equipment load. The drive was furnished, less the clutch, by Edward Byers Co. and included a 10⅝" worm gear, brass worm less bearing mount, spur gears, and Bodine motor.

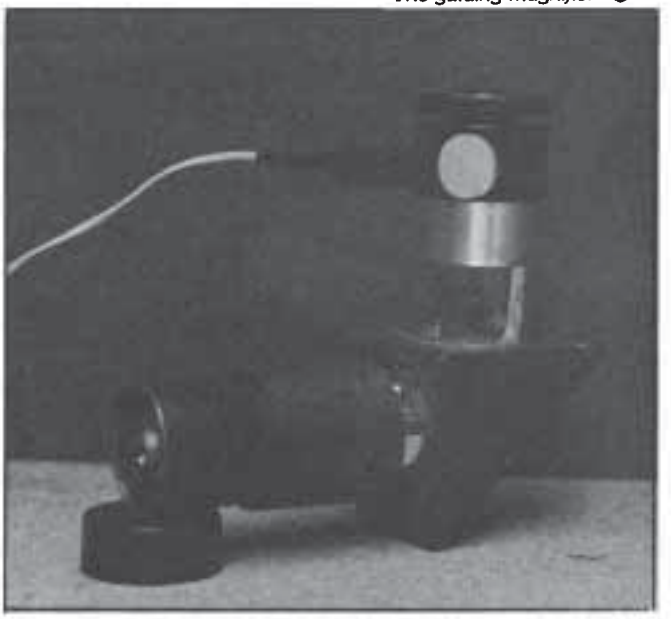
The declination gears were all purchased from the local Boston Gear Co. distributor. The 6" worm gear and stainless steel worm are ground and polished and the 6" and ⅜" spur gears are standard finish. The total cost for all R.A. and Dec. drives was less than $200. The DC declination motor I used is available from Astro-Physics Corp.

The equatorial mounting was constructed from 1" aluminum plate with all sides machined, pinned, and bolted. The R.A. thrust bearing is a pair of 14" diameter iron plates that contact at the perimeter on a 1" surface ring. To reduce friction, two disks of 1/16" teflon sheet were cut and placed between the plates. The lower plate is pinned and bolted to the mount sides. The 3" and 1½" declination bearing surfaces were also lined with sheet teflon. The R.A. polar shaft is provided with a machined brass bushing.

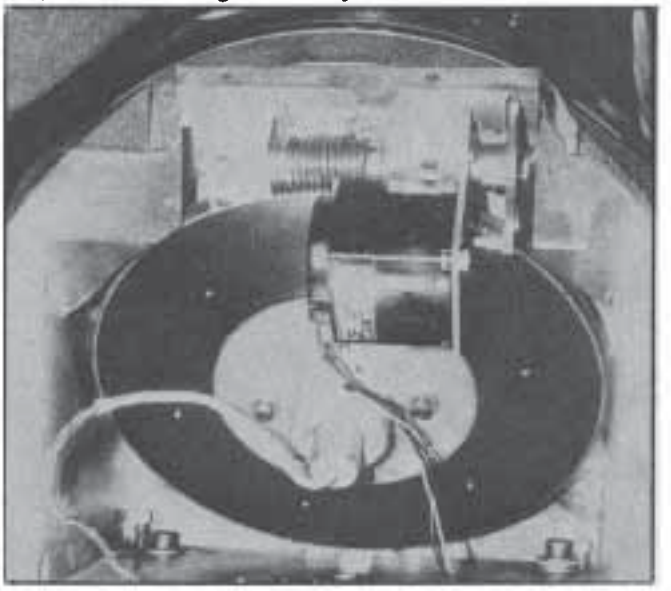
We used teflon rather than conventional roller or ball bearings to eliminate gear play, and the design works as planned. The result is a rock-steady mount capable of high-power guiding even with gusting winds.

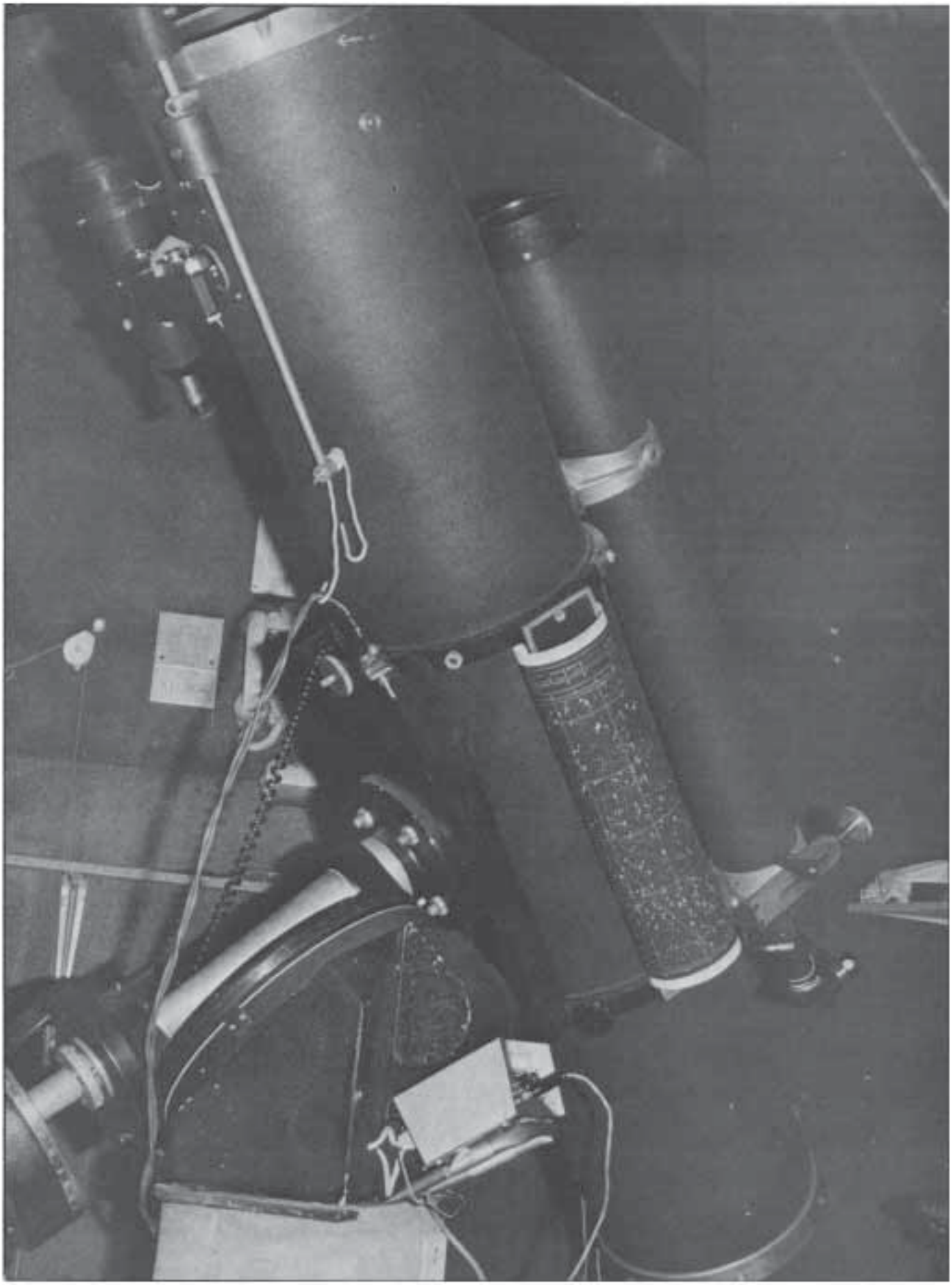
I now had all the equipment needed to take serious pictures and only lacked one small item: an observatory. Most observatories seem to have two things in common. They are functional yet lack aesthetic beauty. In consideration of our country neighborhood, property

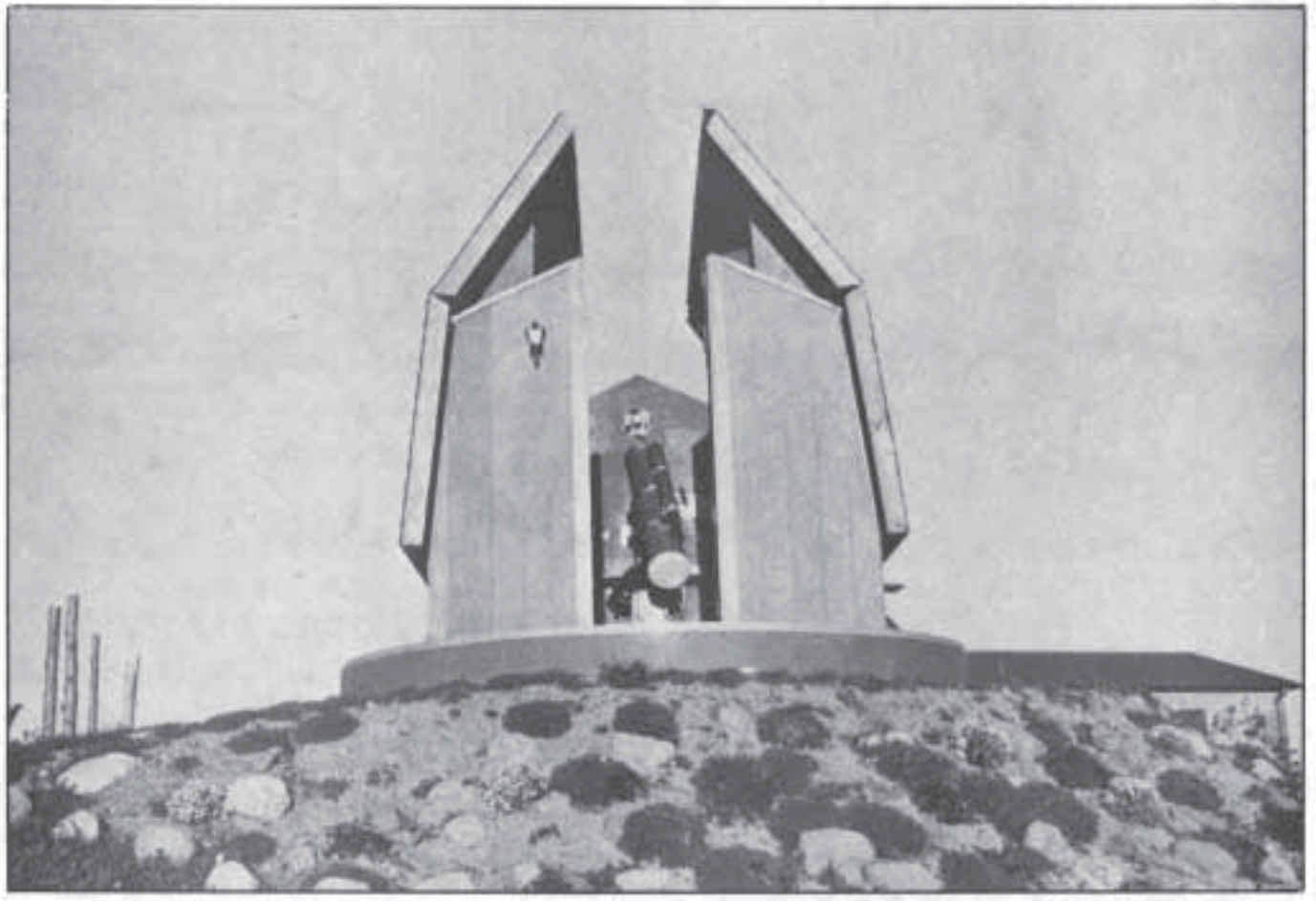
The guiding magnifier



The R.A. drive gear assembly







deep-sky observatory

values, and appearances, I decided to construct an observatory that wouldn't even remotely resemble an observatory. The building would be a properly configured small barn that would rotate about the central independent telescope pier and open to all areas of the sky through a triple door and roof opening. With the help of my wife and two boys, ages 10 & 11, we completed the structure in six weeks. Here are some details.

A 4″ footer was poured to support a 15′ diameter, 8″ block foundation wall. The power, telephone, and intercom lines were also installed at this time. The top of the foundation wall was brought to 4″ above grade level to prevent water and ice from interfering with the foundation and rotating base. A 15′-diameter steel ring of ⅜″ thick 3″ x 5″ angle iron was rolled by a local iron fabricator with the 5″ leg inward for drive and support wheels. Anchors were welded on the bottom and the ring was mortared level onto the concrete block foundation wall. Using this ring, 96″ x 3″ strips of ⅜″ C-D grade plywood were formed into a laminated wood ring 3″ high x 4⅛″ thick with a 14′ 11¼″ outside diameter.

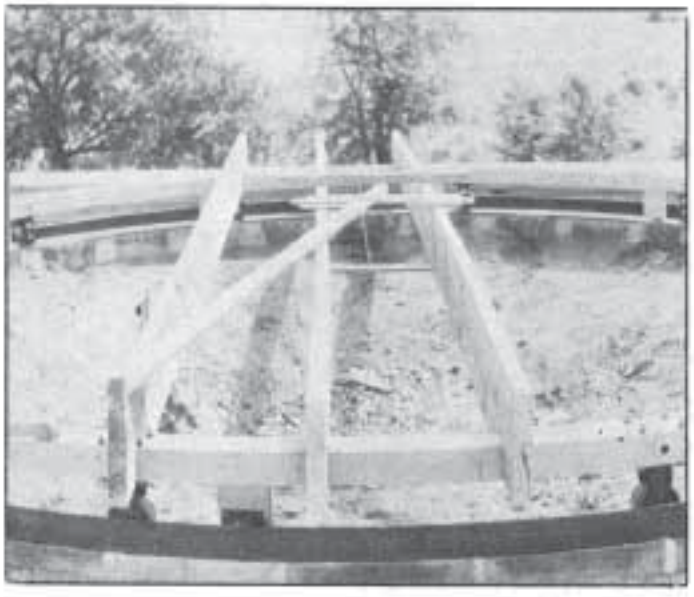
Waterproof glue and thousands of 1¼″ plasterboard nails were used in forming its 11 layers. After prying the wooden ring out of the steel track ring, twelve 800 lb.-capacity steel casters were installed at equal intervals. For guide rollers, twelve 200 lb.-capacity steel casters were initially installed but later proved inadequate to the side loads and were replaced with four 800 lb.-capacity steel casters. The 2 x 10 floor joists were then notched and fastened on 16″ centers to the wooden caster ring. The joists were trimmed to 16′ in diameter. We waited until this stage to install the telescope pier so that we could be sure of final floor height above the pier footer and to check the actual center of base rotation.

A 9′ section of 12″ Sonotube form material was fitted with 2″ PVC pipe wire runs and filled with concrete on top of the 4′ x 4′ x 6′ thick footer which extends 4′ below finished grade. After pouring the pier, the deck was finished with ⅝″ plywood on top and ¼″ plywood on the curved base sides. The 10′ and 12′ by 7′6″ walls were framed up and all the building wiring installed. The exterior walls were paneled with 4′ x 8′ x ⅝″ barn board paneling. The interior walls were paneled with ⅜″

Building up the base ring

laminated base ring

2 x 10 wooden floor joists



deep-sky observatory

particle board and redwood stained to reduce reflections and assist night vision.

The roof sections were identically constructed and fastened to the top wall plate using three extra heavy duty hinges on each side. The roof was then covered with ⅜" sheathing and finished with felt and white self-sealing shingles. The roof opens with the aid of two 1000 lb.-capacity winches, one for each side. Each roof section has a pair of 5' lever arms to which the winch cables are attached. The roof opens to a width of 3', which is the same as the opening of the triple dutch door.

The building is fully ventilated through the top and bottom of the side walls with the assistance of a constantly running gable exhaust fan mounted at the top of the back wall. To prevent snow and dirt accumulations on the steel caster track, a weather seal was fabricated. A piece of indoor-outdoor carpeting 3 feet wide by 53 feet long was purchased with a ½" grass texture. We dug a 4" x 4" deep trench around the perimeter of the rotating base and set one 53' edge of the carpet seal into concrete. The top edge was folded over, grass side facing out and also against the base. Wire stiffeners were used every 16" within the seal to prevent sagging. A 52' length of 12" aluminum flashing was nailed to a ½" plastic hose spacer and over the carpet seal, thus effecting a double seal which has proved very effective. The building is turned with two oppositely-mounted ¼ hp 6-RPM gearmotors which drive 4" rubber wheels. With the roof sections fully opened and acting as wind shields, the observer is well protected and has access to every part of the visible sky.

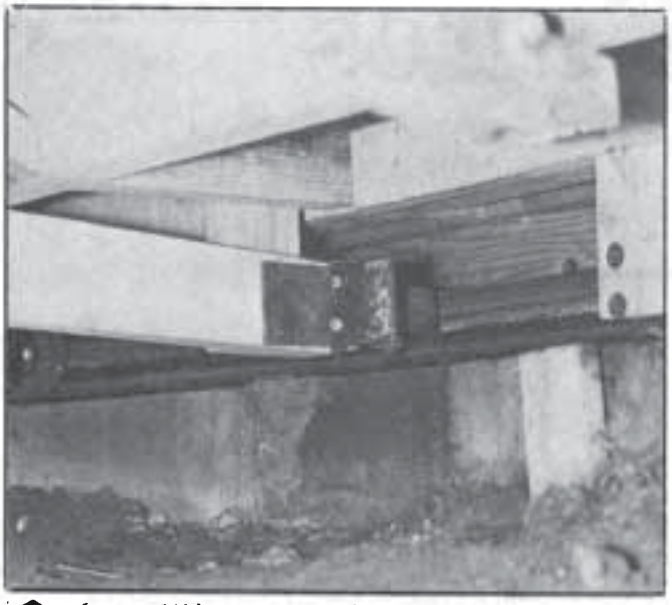
The observatory wasn't enough. To process and then identify all the subjects on the film, we next constructed an up-to-date darkroom and astronomical study. I spend nearly 5 times as much time in the darkroom and study as I do at the telescope. On a typical night, I may photograph 59 galaxies on 7 different exposures. To keep track of them all, I've set up a system for filing and record keeping. I rely strongly on the *Palomar Sky Survey* and the *Zwicky Catalog of Galaxies* for reference, but in addition, I use the *SAO Star Atlas*, its *Catalog of Non-Stellar Objects*, and the *Second Reference Catalogue of Bright Galaxies* by Vaucouleurs.

My sky conditions and equipment are capable of registering images of galaxies to magnitude 17 and stars to magnitude 19. To date I have photographed all the planets and the Messier list with the telescope. I am currently photographing all galaxies north of -30° and brighter than magnitude 13.

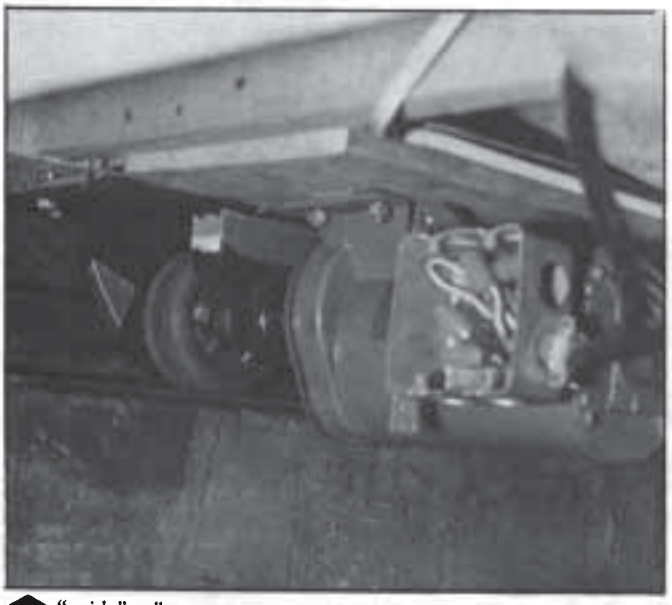
I very much appreciate the assistance given me by the members of the Buffalo Astronomical Association in making my efforts so successful. I will gladly answer any questions or render assistance to any amateur who would like to do serious deep-sky photography.

Thomas L. Dessert
Buffalo Astronomical Association
S-1286 South Anne Dr.
Alden, NY 14004

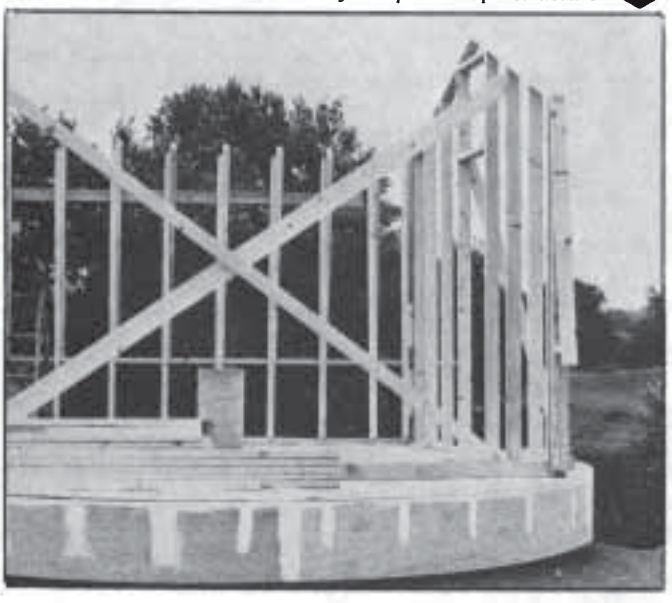
■



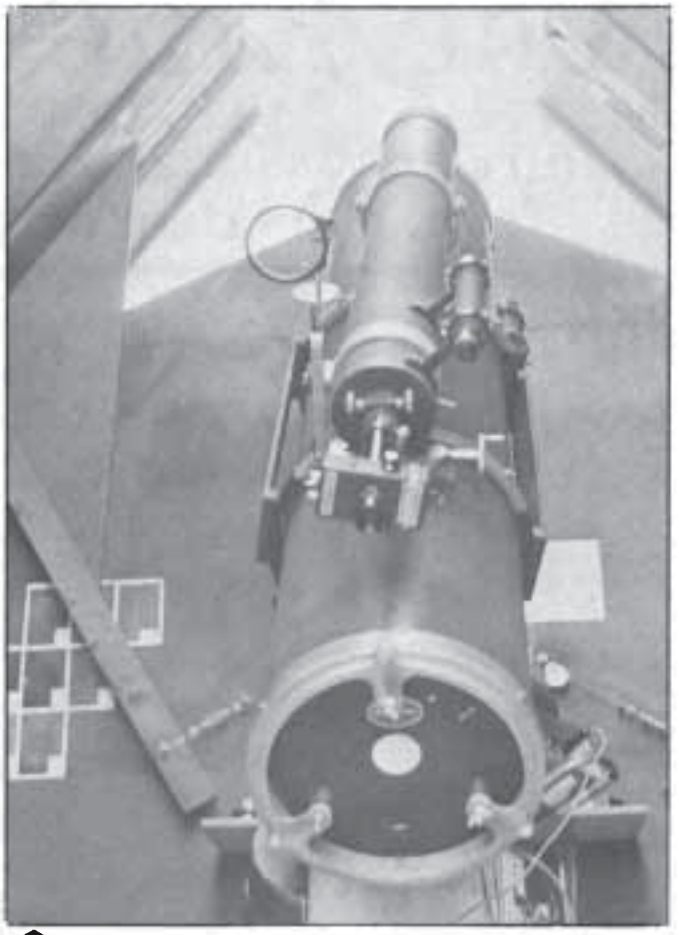
6 r.p.m. 1/4 h.p. gearmotor drive



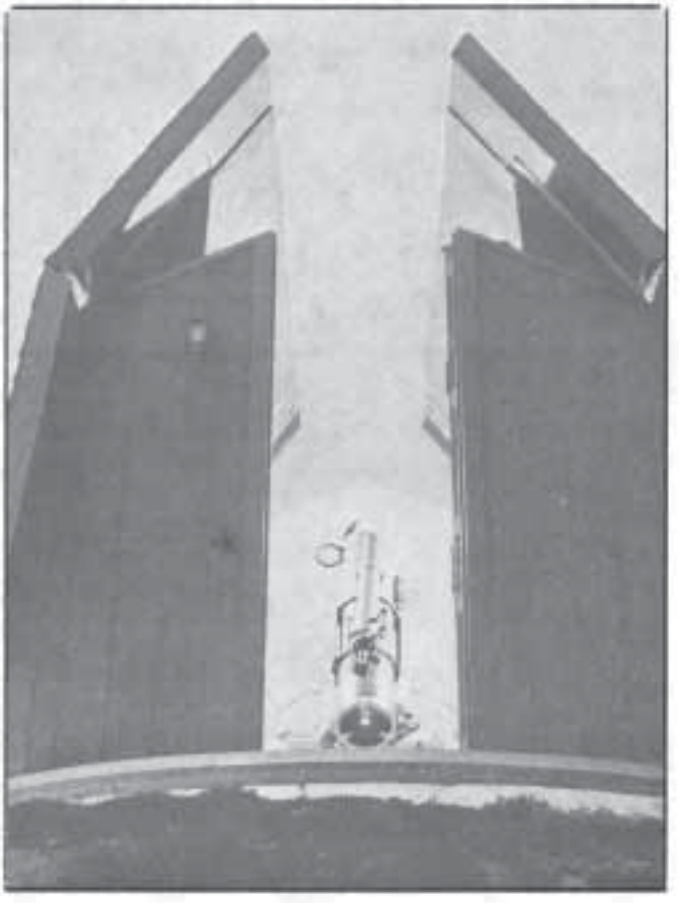
"guide" rollers



Partially completed superstructure



Note the roof-opening mechanism in these two pictures



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a directory to materials and services for the amateur telescope maker

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◄3 Letters

Minarik Sells Motors

Dear Sir / I read with interest Mr. Sandy's account of his difficulties in obtaining a small motor for his declination drive system (described in TM4). I am presently in the process of constructing a spectroheliosope utilizing the design of Frederick Veio of Clearlake Park, California, for which I have needed to purchase several small synchronous motors of low r.p.m. Following Mr. Veio's suggestion, I have obtained my motors from Minarik Electric Co., 224 E. Third St., Los Angeles, CA 90013.

Minarik is a distributor of motors manufactured by Bodine Electric Co., Bristol Saybrook, Hurst, Slo-syn, and several others. I have placed two separate orders with this firm and each time the order has been filled promptly and without difficulty. Interested persons may wish to request their catalog, which includes many other useful items such as gears, clutches, timing devices, and switches.

William A. Miller, Jr.
Louisville, KY

Following in the Footsteps

Dear Sir / TELESCOPE MAKING has aroused in me the same feeling of excitement about telescope making that *ATM-1* did years ago. It is so real. And just look at the skill and dedication that is pouring forth today from "backyard" operations. So many good ideas to try out that I hardly know where to begin.

And the quality of suggestions seems higher than I recall from *ATM-1*. I remember trying to follow instructions in *ATM-1* for mirror making and discovering that if I followed the instructions "to the letter" that I found myself wandering through a series of near disasters (the same wrong routes followed by the authors).

I'm not trying to degrade these earlier efforts; rather I am trying to point out that there is a whole lot more technology available today, and this technology is being used by amateurs. The result is a higher level of precision in project descriptions in TM.

I think you are to be congratulated for bringing this information together. I am sure that if Ingalls were alive today, he too would want to extend his hand to you for your accomplishment with TM.

Keep it going. TM is worth every cent of the subscription and more.

Darryl J. Davis
953 Ordway
Albany, CA 94706

Dear Mr. Davis / Thank you for your comments. What was it that Newton said: "If I can see further, it is only because I stand on the shoulders of giants."

1/4-Wave Not Good Enough?

Dear Mr. Cox / I very much enjoyed the article on schiefspieglers in the latest issue (TM#4) and your comment on their superior performance.

In the past, theoretical discussions on the effects of differing size central obstructions have centered on the total light subtracted from the Airy disk which goes into the diffraction rings. A "perfect" optical system was one with no obstruction having 84% of the total light in the disk and 16% in the rings. With a 0.3 obstruction, this falls to 68% in the disk and 32% in the rings. A telescope with no obstruction and a 1/4-wave OPD also has 68% in the disk and 32% in the rings, either system then just satisfying Rayleigh's criterion. In fact, the MTF curves for two such systems are identical.

A telescope with the usual-size central obstruction present must be of very high quality to give an unobstructed system a "run for the money." Home-built catadioptrics seldom achieve the accuracy required. Also there are only 2 surfaces in a schiefspiegler compared to 4 in a catadioptric.

To determine the practical effects, four observers recently tested a 6" f/15 refractor of high quality (Jaegers) against two 6" f/15 Maksutov-Cassegrains (Quantums). The one Maksutov had enhanced silver coatings, the other had regular aluminum. 16 mm eyepieces were used in all three to give the same magnification and all were in thermal equilibrium. Seeing was good, but not exceptional.

Jupiter and Saturn were examined. The light grasp of the 6" refractor and the enhanced coated Maksutov was practically identical. The other Maksutov didn't come up to the other two in light grasp. Definition was equally good in all three, but the colors in the 6" f/15 Maksutov with the silver coatings were truer and superior to the refractor. Between these two there was no difference in the amount of low contrast detail rendered visible. A slight loss of detail was noticed in the Maksutov that had the aluminum coatings.

Our conclusions were that despite the presence of a 0.33 obstruction, the refractor offered no gain in definition or contrast over the enhanced silver instrument and only a marginal gain over the aluminum coated system. We did notice that any deterioration of the seeing had a more pronounced effect on the images in the Maksutov than the refractor. However, the O-G of the refractor was some 12 or 14 feet off the ground while the Maksutovs were only about 4 feet off the ground.

My conclusion is that many of the past reports on the observing superiority of unobstructed systems over obstructed ones are due primarily to seeing effects, lesser quality optics than are needed (1/4-wave in an obstructed system is simply not good enough!), not critical enough alignment, etc., rather than the central obstruction. If the obstructed systems are made to a very high accuracy, the effects of the C-O (up to 0.3D) are only as bad as a 1/4-wave error and disappear like the boogieman of childhood fairy tales.

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Wandering Spots

Dear Sirs / Please be advised that to my knowledge the computer spot diagrams for my Schmidt-Cassegrain telescope design which appeared in the April 1962 issue of *Sky and Telescope* magazine in no way represent the performance to be expected from other Schmidt-Cassegrain telescope designs or instruments which are currently available.

Ronald R. Willey, Jr.

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photo by Jack Newton

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